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ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

Third Annual Report 710816-10

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This report presents the third annual review of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics, and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies; (4) Time Domain Studies; (5) Adaptive Array Studies; and (6) Laser Induced Transients.

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I. INTRODUCTION

This report presents the third annual summary of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies; (4) Time Domain Studies; (5) Adaptive Array Studies; and (6) Laser Induced Transients.

The following sections summarize the significant accomplishments of the program (Section II) and the research by work unit (Section III). Researchers and their publications are listed under each work unit. A listing of the present research programs at the Laboratory and all reports and papers published by the Laboratory during the past year are given in the appendices.

II. SIGNIFICANT ACCOMPLISHMENTS

The study of the Uniform Geometrical Theory of Diffraction continues to be one of our major efforts. This work is basic to the development of computer codes for calculating the patterns of reflector antennas and antennas on aircraft, missiles, satellies, ships and in other environments, and for calculating the radar cross section of a wide range of objects. In the present period, significant contributions were made in radiation and scattering from impedance loaded surfaces, radiation from antennas mounted close to edges, radiation from antennas on or near structures with vertices (corners) and scattering from finned cylinders of finite length. The radiation studies are helping us to develop more general computer codes on other programs for the analysis of antennas on or near complex structures such as ships and planes. The scattering work is helping on programs involving radar cross section studies and target identification.

Using combined GTD and moment method (hybrid) techniques, a numerically derived solution has been obtained for diffraction from a perfectly-conducting planar surface which is smoothly terminated by a circular cylinder. The solution is valid not only in the region away from the refraction boundary, but also in the region near to it. This solution is very useful in optimizing practical terminations to flat plate structures such as horn antennas. It is now a straightforward procedure to design a horn antenna with curved edges for a specified side-and back-lobe level in the E-plane. The curved transition also helps to match the waveguide feed to the horn and the aperture of the horn to free space resulting in substantially improved bandwidth and VSWR compared to a conventional horn.

Many practical antenna applications involve monopole-type antennas mounted near the edge of a complex surface or structure. A solution has been obtained for a wire antenna mounted near a wedge of arbitrary angle or near a corner, and surface patch modelling of complex shapes has been extended by development of a non-rectangular, or polygonal, patch model. These developments are being used to improve moment method computer codes on other programs for analyzing antennas on complex structures such as buildings, planes, and ships.

In the area of time domain studies, we are predicting scattered waveforms for objects of increasing complexity, finding target dependent excitation waveforms and processing algorithms to identify and optimize responses from specific targets, and determining effects of noise and signal bandwidth on the detection and identification of radar targets. This work has direct application to non-cooperative target recognition.

Work continued in adaptive arrays and the significant accomplishments were the determination of the effects of array and signal parameters on the eigenvalues of the covariance matrix, determination of the effects of antenna element patterns and signal polarization on array performance, and determination of effects of differential time delays on the performance of the LMS loop. This work completes the JSEP support of this program. Continuing support is being provided by NAVAIR under Contract No. N00019-80-C-0181.

A supplemental work unit on laser induced transients was carried out during this period. It had been found on a previous program that an optical pulse from a fast rise-time laser when focused on a metallic surface produced radiation at R.F. In this work unit, exact relations for some standard geometries were obtained between the radiated fields and the current pulse caused by the thermionic emission from the heated surface. This provides more precise estimates of the conversion efficiency and also illustrates the characteristic time-domain signatures radiated by the targets. The efficiencies are such that this technique has potential use as a laboratory tool for obtaining the impulse response of a target.

III. RESEARCH SUMMARY

A. Diffraction Studies

Researchers: R.G. Kouyoumjian, Professor (Phone: (614) 422-7302)
R. Tiberio, Visiting Professor
P.H. Pathak, Research Scientist
N. Wang, Senior Research Associate
T. Jirapunth, Graduate Research Associate

Accomplishments

During the present contract period, the work accomplished in extending the uniform geometrical theory of diffraction (UTD) has been substantial. This is composed of the research and writing which is described in the sections to follow.

1. Diffraction at Convex Surfaces

a. Perfectly-conducting surfaces

During the past year several papers have been written and submitted for publication which describe Uniform GTD solutions for the diffraction by perfectly-conducting convex surfaces. The papers treat the radiation from sources both off and on a convex surface and the mutual coupling between sources on a convex surface; they are:

"A Uniform GTD Analysis of the Scattering of Electromagnetic Waves by a Smooth Convex Surface" by P.H. Pathak, W.D. Burnside, and R.J. Marhefka; IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 5, September 1980, pp. 631-642.

"A Uniform GTD Solution for the Radiation from Sources on a Perfectly-Conducting Convex Surface" by P.H. Pathak, N.N. Wang, W.D. Burnside, and R.G. Kouyoumjian; accepted for publication by the IEEE Transactions on Antennas and Propagation.

"Ray Analysis of Mutual Coupling Between Antennas on a Convex Surface," by P.H. Pathak and N.N. Wang; accepted for publication by the IEEE Transactions on Antennas and Propagation.

b. The radiation and scattering from cylindrical surfaces with a surface impedance loading

A study of the electromagnetic scattering from a cylindrical surface with impedance loading is of interest in that it provides an understanding of the effects of the impedance loading on the scattered fields. An interesting application is to control the electromagnetic scattering characteristics from conducting bodies such as an aircraft, missile, satellite, etc. Also, it is useful in the radar cross section calculations of structures made of composite materials or conducting bodies coated with absorber materials.

During the first year of a three-year research program for the basic diffraction studies, the electromagnetic scattering from an infinitely long circular cylinder with a constant surface impedance and illuminated by a normally incident plane wave was studied. Unlike the perfectly-conducting case, it was found that the impedance cylinder (i.e., a cylinder with a constant surface impedance) exhibits a strong resonance phenomena in the radar cross section. We have developed a high frequency solution for the problem and were able to demonstrate vividly the cause of the resonance. A paper entitled "Regge Poles, Natural Frequencies and Surface Wave Resonance of a Circular Cylinder with a Constant Surface Impedance", by Nan Wang, was presented at the International IEEE/APS Symposium in Quebec, Canada, held on June 2-6, 1980.

It was found that surface waves with almost pure imaginary propagation constant traverse around the cylinder surface with negligible attenuation, and interfere with each other constructively such that they add in phase to give the distinctive resonance phenomena in the radar cross section. Numerical values for the propagation constant of the surface wave, which are related to the Regge poles of the impedance cylinder, have been found. Also, criterion for predicting resonance has been established and the correlations between the resonance, the Regge poles, and the natural frequencies of the impedance cylinder have been demonstrated. Work is now in progress to extend these results to a conducting cylinder coated by a dielectric layer of uniform thickness.

c. Partially-coated perfectly-conducting surfaces

Two papers have been written on the asymptotic high-frequency radiation from a magnetic line source or a magnetic line dipole located on a uniform impedance surface which partially covers a perfectly-conducting surface. This work is of interest in the study of fuselage mounted airborne antennas where, for example, it may be desired to increase the radiation near the horizon or shadow boundary. These papers are:

"An Approximate Asymptotic Analysis of the Radiation from Sources on Perfectly-Conducting Convex Cylinders with an Impedance Surface Patch" by L. Ersoy and P.H. Pathak; to be submitted for publication to the IEEE Transactions on Antennas and Propagation.

"Ray Analysis of the Radiation from Sources on Planar and Cylindrical Surfaces with an Impedance Surface Patch" by P.H. Pathak and L. Ersoy; to be submitted to J. Radio Science.

In the second paper, the impedance surface is assumed to be such that it always supports a surface wave mode for a given source. The surface wave diffraction effects are calculated via the uniform GTD (or UTD) which employs uniform diffraction coefficients. The latter are found from the Wiener-Hopf solutions to canonical problems of surface wave diffraction by a planar two-part surface. The first paper removes the limitations placed in the analysis pertaining to the second paper in that it is also valid for impedance surfaces which do not support a surface wave-type mode.

A natural extension of the work reported in the first paper is to treat the corresponding scattering problem where the source is no longer positioned on the surface with the impedance patch (or, alternatively, this structure may be illuminated by a plane wave). A study of the scattering from such a surface is of value in that it provides an understanding of the effect of the impedance loading on the scattered fields. An interesting application is to control the electromagnetic scattering from conducting bodies such as an aircraft, missile, or a satellite, etc. Also, it is useful in the radar cross section calculations of structures made of composite materials or of conducting bodies coated with absorber materials. This study will be initiated in the near future.

d. Slope diffraction for convex surfaces

An asymptotic high frequency solution for the diffraction by a convex surface illuminated by a ray-optical field with a slow spatial variation at and near the point of diffraction on the shadow boundary has been developed recently, as described earlier in part 1a. This solution should be extended to the case where the incident field has a rapid spatial variation near this point. The results of this analysis are useful in studying the pattern effects of antennas from the diffraction by convex bodies, e.g., the shadowing effects of an aircraft fuselage on the radiation from a wing- or tail-mounted array or of a ship mast on the radiation from a nearby shipboard antenna.

The extension has been carried out for two-dimensional geometries by considering the illumination of a circular cylinder by a line source doublet positioned so that its field vanishes at the point of diffraction. At present, this solution is being generalized to three-dimensional geometries where the rapidly-varying incident field emanates from a point source. Finally, the slope diffraction solution will be extended to the case of electromagnetic fields illuminating perfectly-conducting convex surfaces.

2. Extensions of Edge Diffraction

a. Edge illumination by non ray-optical fields

i) Transition region fields incident on the edge

Several papers have been written on the diffraction by a pair of nearby, parallel edges, where one edge lies on the shadow boundary of the other. A configuration of this type may be a part of practical antenna and scattering geometries. The solution to this problem requires an extension of the Uniform GTD, which is valid only for ray-optical fields incident on the edge, because the shadow boundary field illuminating the second edge is not a ray-optical field. These papers are:

"A Uniform GTD Solution for the Diffraction by Strips Illuminated at Grazing Incidence" by R. Tiberio and R.G. Kouyoumjian, J. Radio Science, pp. 933-941, November-December 1979.

"An Analysis of Diffraction at Edges Illuminated by Transition Region Fields" by R. Tiberio and R.G. Kouyoumjian; submitted to J. Radio Science.

"Calculation of the High-Frequency Diffraction by Two Nearby Edges Illuminated at Grazing Incidence" by R. Tiberio and R.G. Kouyoumjian; submitted to the IEEE Transactions on Antennas and Propagation.

No further work on this subject is planned for the year ahead, except possibly for some applications of the dyadic diffraction coefficient for the double diffraction from a pair of nearby edges illuminated at grazing incidence.

ii) Source close to an edge

In the conventional form of the uniform GTD, it is assumed that the incident field is a ray-optical field, which implies that it is polarized in a direction perpendicular to the incident ray. In general, this requires that the source of the incident field be sufficiently far from the point of diffraction that the component of the incident field parallel to its ray path (the component in the radial direction from the source) is negligible at the diffraction point. However, in some applications this is not the case, e.g., a monopole antenna may be mounted at or very close to the edge of a ship or the edges of wings and stabilizers. This case is also of interest in the development of the hybrid GTD/moment method solution, where it is desired to calculate the input impedance of a wire antenna close to an edge.

An asymptotic solution for the diffraction of the fields of electric and magnetic dipoles close to the edge of a wedge has been obtained. The analysis proceeds as done earlier in developing improved wedge diffraction coefficients [1], except that the radial component of the incident field is included which makes it necessary to include higher order terms in the asymptotic approximation. In the present Uniform GTD expression, the field point must be far from the point of diffraction on the edge. An attempt is being made to overcome this limitation by representing the field of a dipole close to the edge by a spectrum of plane waves. The resulting integral representation for the diffracted dipole field would then be asymptotically approximated to obtain the desired solution. It should be noted that the field close to the edge can be calculated for plane wave illumination.

A second method for removing the aforementioned limitation is to employ a convergent, spherical wave representation for the field of a dipole close to an edge. This solution has been obtained as a result of our work on vertex diffraction (see Section 3). It is hoped that the spherical wave solution can be combined numerically with the asymptotic solution so that we will have a more useful computational algorithm for edge diffraction.

From the local behavior of edge diffraction, one expects to be able to extend these solutions to curved wedge geometries and to use them to calculate the radiation from complex structures.

b. Edge-excited surface rays

A paper entitled "A Uniform GTD Analysis of Edge-Excited Surface Rays" by P.H. Pathak and R.G. Kouyoumjian is being written; it will be submitted to the IEEE Transactions on Antennas and Propagation.

This paper describes a Uniform GTD analysis of surface diffracted rays which are excited by a curved edge in an otherwise smooth convex surface. Such a curved wedge configuration occurs as a part of many practical antenna and scattering shapes, e.g., the base of conical and cylindrical structures, and the trailing edge of wings and stabilizers.

The excitation of surface waves on a convex surface can be associated with an "equivalent current" located at the edge. The strength of this equivalent current is shown to be directly related to the field of the edge diffraction space ray. Its strength is fixed to its value at the shadow boundary when calculating the surface diffracted field in the shadow region, whereas it changes according to the Kouyoumjian-Pathak edge diffraction coefficient [2] when calculating the field in the lit region (i.e. on the lit side of the surface shadow boundary). Thus, in the lit region, this solution reduces uniformly to the usual edge diffracted space ray field outside the surface shadow boundary transition region even though it depends on the nature of the convex surface near the edge for field points in the shadow as well as the lit portions of this transition region. The present solution does not include the case where there is a confluence of edge and curved surface shadow boundaries; this case is being investigated and it forms a part of the future research.

The present solution can be readily extended to the concave surface of a curved wedge. The equivalent edge currents are now used to determine the field of the mixture of space rays and whispering gallery modes which have been prescribed by Felsen [3]. Note that the space rays are, in general, multiply reflected from the concave surface.

c. Slope diffraction for edges

If the field incident on the edge of a perfectly-conducting wedge does not have a rapid spatial variation transverse to the direction of incidence, the diffracted field is directly proportional to the field incident at the edge, and it can be calculated using the Kouyoumjian-Pathak edge diffraction coefficient [2]. However, if the field incident on the edge has a rapid spatial variation, a second term is required. This is proportional to the spatial derivatives of the incident field at the edge and is known as the slope diffraction term. The slope diffraction term ensures that the spatial derivatives of the pattern function are continuous at the shadow and reflecting boundaries, so that there are no "kinks" in the calculated high-frequency pattern. The need for a higher order term of this type may also arise in the case of diffraction at a convex surface, as was pointed out in Section 1d.

We have employed several methods to obtain the dyadic slope diffraction coefficient for an ordinary wedge, and although this coefficient has been reported in the literature [4], its derivation has not been published. Recently, some higher order terms, which are proportional to the second spatial derivatives of the incident field, have been obtained. Also, we have generalized our expression for slope diffraction to the curved wedge, i.e., a wedge formed by intersecting curved surfaces. A paper describing this work is in preparation.

d. Diffraction by a thin dielectric half-plane

The diffraction by a thin dielectric half plane is an important canonical problem in the study of the diffraction of electromagnetic waves by penetrable bodies with edges. The excitation for this problem can be either an electromagnetic plane wave, or a surface wave incident along the dielectric surface; both types of excitation are considered. For sufficiently thin dielectric half-planes, solutions based on the Wiener-Hopf technique can be obtained if one approximates the effect of the thin dielectric slab by an impedance boundary condition. This analysis begins by bisecting the semi-infinite dielectric half-plane by an electric wall in the first case, and by a magnetic wall in the second case. The problem of plane (or surface) wave diffraction by the dielectric half-plane is then constructed by appropriately superimposing the corresponding solutions for the electric and magnetic wall bisections, respectively. This procedure is expected to yield a dielectric half-plane diffraction coefficient which is better than that obtained recently by Anderson for the case when the incident plane wave electric field is parallel to the edge of the thin dielectric half-plane [5], because the latter analysis employs an approximate "equivalent" polarization current sheet model for the thin dielectric half-plane. The approximation in [5] contains only a part of the information present in the more general approach being employed in our work; consequently, it is found that the analysis in [5] yields a diffraction coefficient which is valid only for an extremely thin dielectric half plane. Furthermore, the equivalent polarization current approximation leads to a more complicated Wiener-Hopf analysis when the magnetic field is parallel to the edge; the latter case has not been treated by Anderson [5]. It is also noted that the Wiener-Hopf factors for the case treated by Anderson [5] do not appear to be well behaved for near edge on plane wave incidence cases. In contrast, the Wiener-Hopf factors being employed in our work are based on Weinstein's factorization procedure [6] which overcomes the difficulties present in [5].

At the present time, the diffraction coefficients for the two-dimensional case of both TE and TM plane wave excitation of the thin dielectric half-plane have been obtained, and they are being tested for accuracy. The case of TE and TM surface wave excitation of the thin dielectric half-plane is currently being analyzed.

The present solution is in a form which suggests an ansatz for extending the thin dielectric half-plane diffraction coefficient to the case of a moderately thick dielectric half plane. This extension and the extension to the three-dimensional case can be built up from the two-dimensional solutions. The above extensions will be pursued in the future phases of this work.

3. Vertex Diffraction

In many practical antenna problems one encounters situations where an antenna radiates in the presence of finite, planar structures with edges which terminate in a vertex (or corner), e.g., an antenna radiating in the presence of a finite, rectangular ground plane. Also, flat plates with edges are used in the modeling of aircraft wings and vertical or horizontal stabilizers for analyzing on-aircraft antenna patterns. In the above problems, the antenna pattern is affected by the diffraction of electromagnetic waves not only by the edges, but also by the vertices or corners. Thus, the analysis of vertex diffraction is an important problem.

A formally exact eigenfunction solution has been obtained earlier at the ElectroScience Laboratory [7]; however, this solution is not given in terms of simple functions and it is, therefore, quite difficult to implement in the GTD format. Nevertheless, this convergent solution is of great value in numerically checking approximate high-frequency solutions obtained by asymptotic methods. More will be said about this later in this section.

Approximate, asymptotic high-frequency solutions to the vertex or corner diffraction problem have been presented for the acoustic case [8,9]. While these solutions constitute a first step in obtaining useful solutions, they are not uniform in that the vertex diffraction coefficient obtained is not valid along the vertex and edge shadow boundaries where the edge and vertex diffracted fields assume their greatest magnitude and importance. Some initial work on vertex diffraction recently pursued at the ElectroScience Laboratory has led to a simple, approximate vertex diffraction coefficient which appears to work reasonably well for certain cases. However, this result has been obtained heuristically, and it needs to be improved in order for it to be useful in the general situations encountered in practice; nevertheless, this diffraction coefficient offers some clues for constructing the more refined and useful vertex diffraction coefficient, which we expect to obtain from asymptotic analysis.

The canonical geometry presented in Figure A-1 locally models a typical vertex in a finite, planar, perfectly-conducting surface. In general, a vertex in a planar surface is formed by the intersection of two otherwise smooth, curved edges which constitute two of the other boundaries of the surface. The angle α, shown in Figure A-1, is the internal angle enclosed by the tangents at the vertex to each of the two intersecting curved edges.

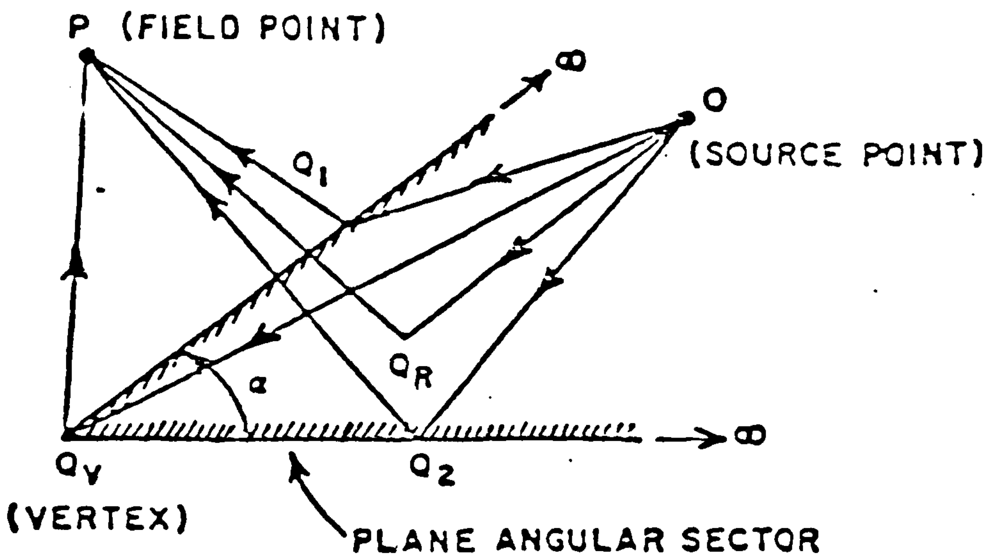

Figure A-1. Various rays associated with the diffraction of waves by a plane angular sector.

The asymptotic high-frequency analysis of electromagnetic vertex diffraction is rather complicated. Vertices not only shadow the incident field, but they also shadow the edge diffracted fields. The shadow boundary of an edge diffracted field is a conical surface whose tip coincides with the vertex and whose axis is an extension of the shadowed edge. The vertex introduces a diffracted ray which penetrates the shadow regions; moreover, the vertex diffracted field must also compensate the discontinuities in the incident and edge diffracted fields at their shadow boundaries. At these boundaries the vertex diffracted field assumes its largest magnitude and, hence, its greatest importance. If the vertex diffracted field is omitted in the GTD solution, then substantial discontinuities connected with the shadowing of the incident and edge diffracted fields may occur in the calculated radiation pattern.

As was mentioned earlier, a convergent solution would be valuable in checking the diffraction coefficient obtained by asymptotic methods. Therefore, work is being carried out to accurately determine the dyadic Green's function for the plane angular sector. As explained below, this largely reduces to an eigenvalue problem of the Lame equations.

To find the free space dyadic Green's function we begin by expanding it in terms of a complete set of vector wave functions which are solutions of the vector wave equation along with the radiation condition and the boundary conditions at the surface of the sector. The vector wave functions are, in turn, expressed in terms of scalar wave functions which are solutions to the scalar wave equation with the appropriate boundary conditions. Both Neumann and Dirichlet type boundary conditions must be satisfied to yield a complete set of vector wave functions. The final step of the solution involves separating the scalar wave equation in the sphero-conal coordinate system. The resulting separated equations include the spherical Bessel equation and two Lame' equations (one with periodic boundary conditions and the other with nonperiodic ones) which are coupled through the two eigenvalues which are actually the separation constants. It is precisely these eigenvalue pairs which serve as the summation index of the free space dyadic Green's function solution.

The solution is thus ultimately reduced to solving for the eigenvalues and eigenfunctions of the separated Lame equations. It is then a straightforward procedure to construct the vector wave functions and hence the free space dyadic Green's function. Once this is found, one can proceed to investigate a wide variety of problems because of the versatility and general nature of the Green's function solution.

4. Finned Cylinders

A high-frequency analysis is being developed for analyzing the backscatter from a perfectly-conducting finite length circular cylinder with identical planar fins placed equally apart near one of its ends. This configuration is illuminated by an arbitrarily polarized electromagnetic plane wave which is obliquely incident on the cylinder. Away from the nose-on and tail aspects, an approximate solution to this problem can be synthesized from the Uniform GTD (UTD) solutions to two related problems; namely, the backscatter from a finite length circular cylinder without fins, and the backscatter from a two-dimensional circular cylinder with a single fin. The solution to the first problem employs the uniform edge diffraction coefficients given by Kouyoumjian and Pathak [2]. This solution remains valid even within the caustic regions (near nose-on and tail aspects) for the finite cylinder; also, the diffraction from the two ends of the cylinder properly combine to yield a bounded and continuous field for aspects at and near broadside. The other solution for the two-dimensional circular cylinder with a fin also employs the uniform edge diffraction coefficient together with a recently developed uniform solution for the diffraction by a convex cylinder given by Pathak [6]. The total backscattered field would then consist of the UTD fields backscattered by the finite cylinder alone and a "modified" physical optics result for the field backscattered from each of the visible fins. In the latter case, the fin contribution essentially consists of the UTD fin scatter result pertaining to an effective 2-D cylinder with a fin, but modified by a factor that accounts for the 3-D nature of the fin. Thus, the important field interactions between the fins and the cylinder are taken into account in contrast with the previous high frequency treatment of this problem. Calculations of the echo area based on this solution will be compared with measured values. Typically, three or four finned cylinders will be studied in this work. Some preliminary results of this work were presented recently in the form of two oral papers, namely:

"A Uniform GTD Analysis of the Backscatter from Finned Cylinders," by P.H. Pathak, R.G. Kouyoumjian, and T. Jirapunth; paper presented at the IEEE International Antennas and Propagation Symposium held at the Laval University, Quebec, during June 2-6, 1980.

"A High Frequency Analysis of the Backscatter from Finned Cylinders of Finite Length," by T. Jirapunth, P.H. Pathak, and R.G. Kouyoumjian; paper presented at the URSI Symposium (held jointly with the IEEE Antennas and Propagation Symposium) held at the Laval University, Quebec, during June 2-6, 1980.

5. Caustic Field Analysis

The GTD is a very convenient and accurate procedure for analyzing high frequency radiation, scattering, and diffraction problems. However, the GTD suffers from a limitation inherent in ray methods; namely, it cannot be employed directly to evaluate fields at and near focal points or caustics of ray systems. The field at caustics must, therefore, be found from separate considerations [11, 12].

In certain problems such as in the diffraction by smooth, closed convex surfaces or by surfaces with a ring-type edge discontinuity, it is possible to employ the GTD indirectly to evaluate the fields in the caustic regions via the equivalent ring current method [13, 14]. However, even the equivalent ring current method fails if the incident or reflection shadow boundaries contain a caustic.

The recently developed uniform GTD solution for the diffraction of waves by a convex surface, as described in Section 1a, offers clues as to how it may be employed indirectly to obtain the far zone fields in caustic regions where the surface is illuminated by a distant source. In the latter case, the shadow boundary and caustic transition regions tend to overlap. In the present work, it has been found that the far zone fields in the near axial direction of a closed surface of revolution illuminated by an axially directed plane wave can be expressed in terms of an equivalent ring current contribution plus a dominant term which may be interpreted as an "effective aperture integral". The latter integral can be evaluated in closed form. In the near zone, where the shadow boundary and caustic directions are sufficiently far apart, only the equivalent ring current contribution should remain significant. This solution will be extended later to include more general cases of non-axial incidence and also arbitrary, closed convex surfaces. In the later phases of this work, we will also consider a few other interesting and useful problems involving caustic field analysis.

Publications and Presentations

1. Articles

Please refer to the section entitled "Accomplishments", which describes the progress to date on the research topics together with the list of publications.

2. Oral Presentations

a. "A Uniform GTD Analysis of the Backscatter from Finned Cylinders," by P.H. Pathak, R.G. Kouyoumjian, and T. Jirapunth; paper presented at the IEEE APS and URSI Symposium which was held at Laval University, Quebec, Canada, during June 2-6, 1980.

b. "A High Frequency Analysis of the Backscatter from Finned Cylinders of Finite Length," by T. Jirapunth, P.H. Pathak, and R.G. Kouyoumjian; paper presented at the IEEE APS and

URSI Symposium which was held at Laval University, Quebec, Canada, during June 2-6, 1980.

c. "An Extension of the Uniform GTD to the Diffraction by a Wedge Illuminated by a Dipole Close to Its Edge," by R. Tiberio, G. Pelosi, and R.G. Kouyoumjian; paper presented at the IEEE APS and URSI Symposium which was held at Laval University, Quebec, Canada, during June 2-6, 1980.

d. "Regge Poles, Natural Frequencies, and Surface Wave Resonances of a Circular Cylinder with a Constant Surface Impedance," by N. Wang; presented at the IEEE APS and URSI Symposium which was held at Laval University, Quebec, Canada, during June 2-6, 1980.

3. Invited Lectures

"The Modern Geometrical Theory of Diffraction," presented by R.G. Kouyoumjian at the Department of Electrical and Computer Engineering, Syracuse University, on October 24, 1980.

References

[1] Pathak, P.H. and R.G. Kouyoumjian, "The Dyadic Diffraction Coefficient for a Perfectly-Conducting Wedge," Report 2183-4, June 5, 1974, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract AF19(628)-5929 for Air Force Cambridge Research Laboratories. (AD707827)

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B. Hybrid Techniques

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G.A. Thiele, Associate Professor*

Dr. C. Chuang, Senior Research Associate

S. Goad, Graduate Research Associate

L. Henderson, Graduate Research Associate

Accomplishments

A numerically derived solution of the diffraction coefficient for a perfectly-conducting planar surface which is smoothly terminated by a circular cylinder has been obtained using the hybrid approach which combines the moment method (MM) with the geometrical theory of diffraction (GTD). This solution is valid not only in the region away from, but also in the region near, the refraction boundary.

The accuracy and usefulness of this solution is demonstrated as it is applied to analyze a novel horn design which provides significantly better performance in terms of the pattern, impedance, and frequency characteristics than normally obtainable. The basic concept utilizes an ordinary horn except that curved surface sections are attached to the outside of the aperture edges forming a junction which is smooth to the touch, as shown in Figure B-1.

Recall that Russo, et al., [1] used the edge diffraction solution to obtain the E-plane pattern of a conventional horn. The same mechanisms are appropriate to analyze the "aperture-matched" horn if the planar/curved surface diffraction coefficients are substituted for the edge terms. Using the three GTD terms illustrated in Figure B-1, some calculated E-plane horn patterns are compared with measured results in Figure B-2. Note that even though the background reflection level of our

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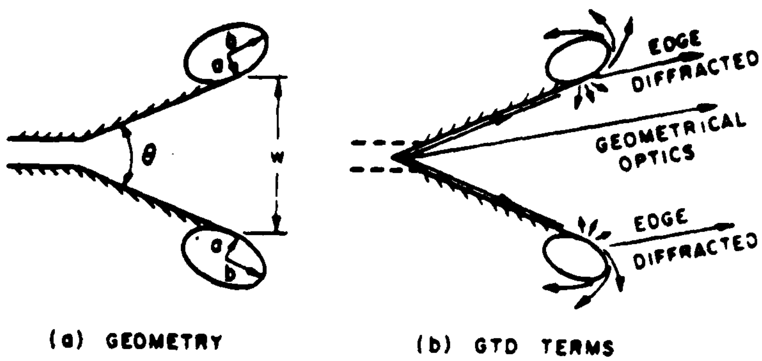

Figure B-1. "Aperture-matched" horn geometry using elliptical shaped curved sections and GTD pattern analysis model.

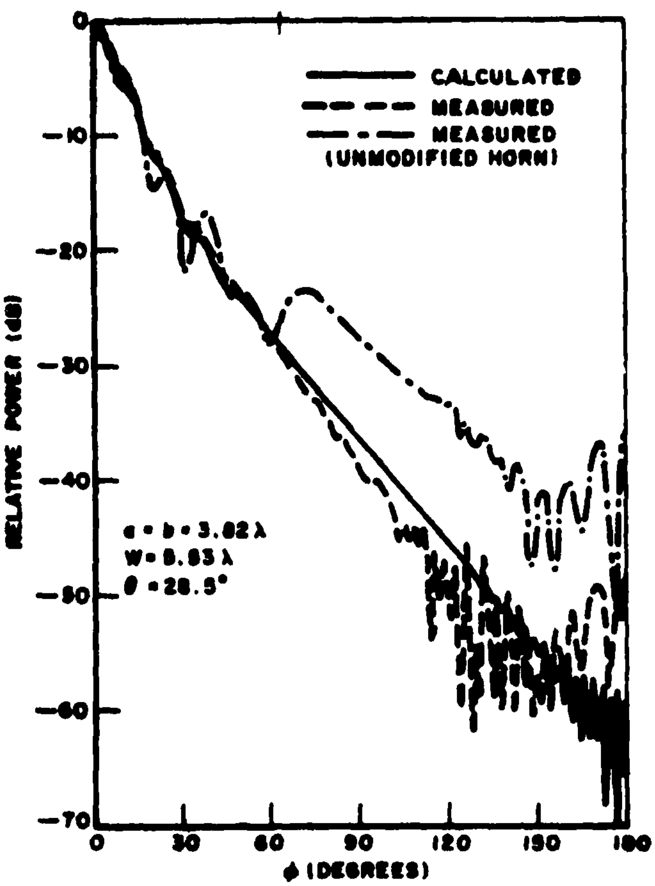

Figure B-2. E-plane pattern of "aperture-matched" horn.

anechoic chamber exceeded that of the "aperture-matched" horn back lobe as illustrated in Figure B-2, its patterns are much smoother and the back lobe is greatly reduced compared to a conventional horn. Actually, this curved surface modification provides this improvement by forming an aperture match between the horn modes and free space such that the energy flows essentially undisturbed across the junction, around the curved surfaces, and into space.

The E-plane pattern illustrated in Figure B-2 is reminiscent of that obtained using a corrugated horn. Thus, it is interesting to compare the "aperture-matched" and corrugated horns assuming that they both fit within the same volume. Note that the corrugated horn and associated data are taken from Reference [2]. Various E-plane patterns are shown in Figure B-3, which illustrate that the "aperture-matched" horn has a much smoother pattern and lower back lobe than the conventional horn; yet, it does not provide the same reduction in the wide side lobes as compared with the corrugated horn. This implies that one would have to increase the overall horn size in order to achieve nearly the same E-plane pattern.

Provided the "aperture matched" and corrugated horn modifications are only applied to the E-plane edges, the H-plane patterns of the "aperture-matched" and corrugated horns are virtually the same as that for a conventional horn except for a greatly reduced back lobe level. Using the same horns, the back lobe level as a function of frequency is shown in Figure B-4. At the lower end of the frequency band the corrugated horn has a lower back lobe; whereas, the "aperture-matched" horn has superior performance at the high end. Both the "aperture-matched" and corrugated horns are significantly better than the conventional horn.

The beamwidth for the various horns is illustrated in Figure B-5. As one might expect, the beamwidth for the conventional horn is smallest due to the uniform distribution across the complete aperture plane; whereas, the corrugated and "aperture-matched" horns have tapered distributions. The "aperture-matched" horn has much better frequency performance

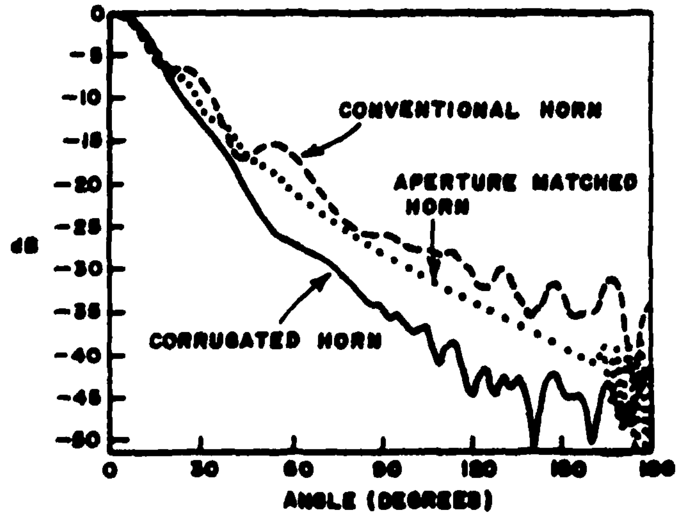

Figure B-3. Various E-plane horn patterns. The "aperture-matched" horn pattern is calculated and the others are measured.

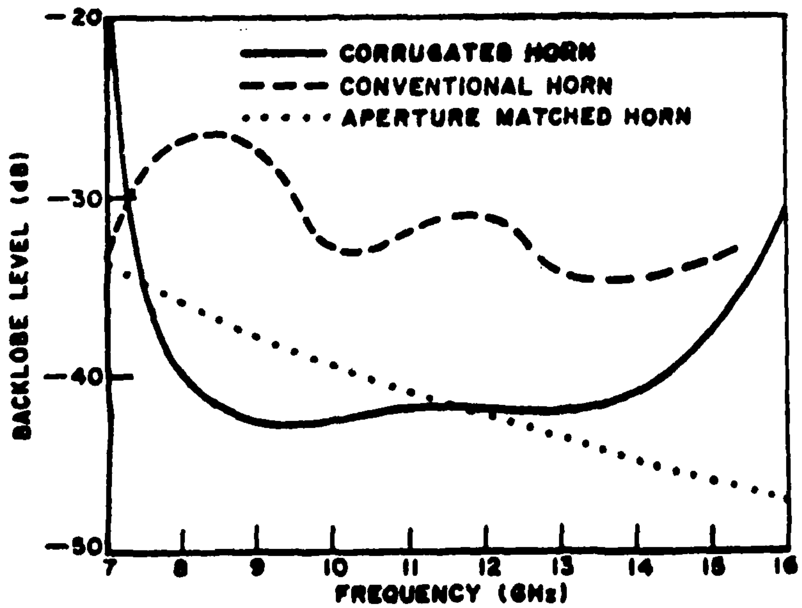

Figure B-4. Back lobe level as a function of frequency. The "aperture-matched" horn data are calculated and the others are measured.

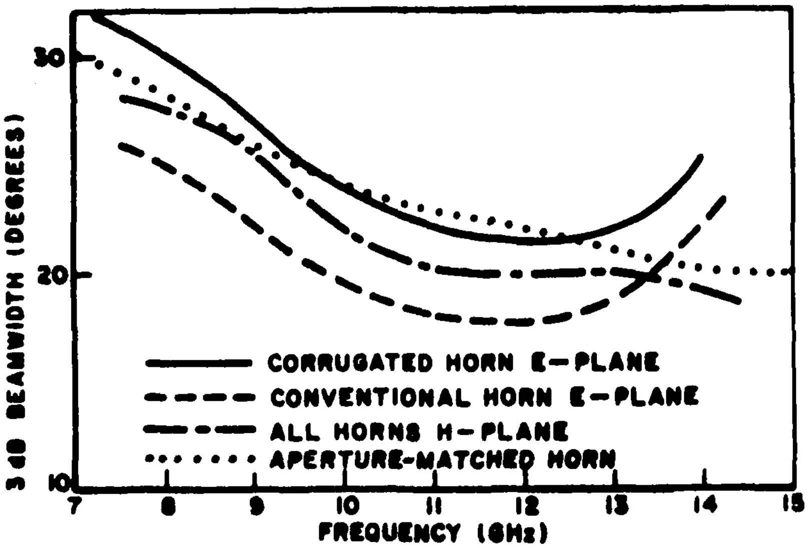

Figure B-5. Three decibel beamwidth versus frequency. The "aperture-matched" horn data are calculated and the others are measured.

than a dual-mode, corrugated or conventional horn. This statement is justified based on the E-plane horn patterns shown in Figure B-6.

The physical limitations of the "aperture-matched" horn remain a concern in that the curved surfaces may significantly increase the outside dimensions of the horn. To partially solve this size and weight problem, it is suggested that quadrant elliptic sections be attached to the aperture edges. Using such structures, the aperture width is not greatly increased, and yet one obtains superior E-plane patterns.

Reflection from the aperture back into the horn is greatly reduced using the "aperture-matched" horn. In that the aperture reflection

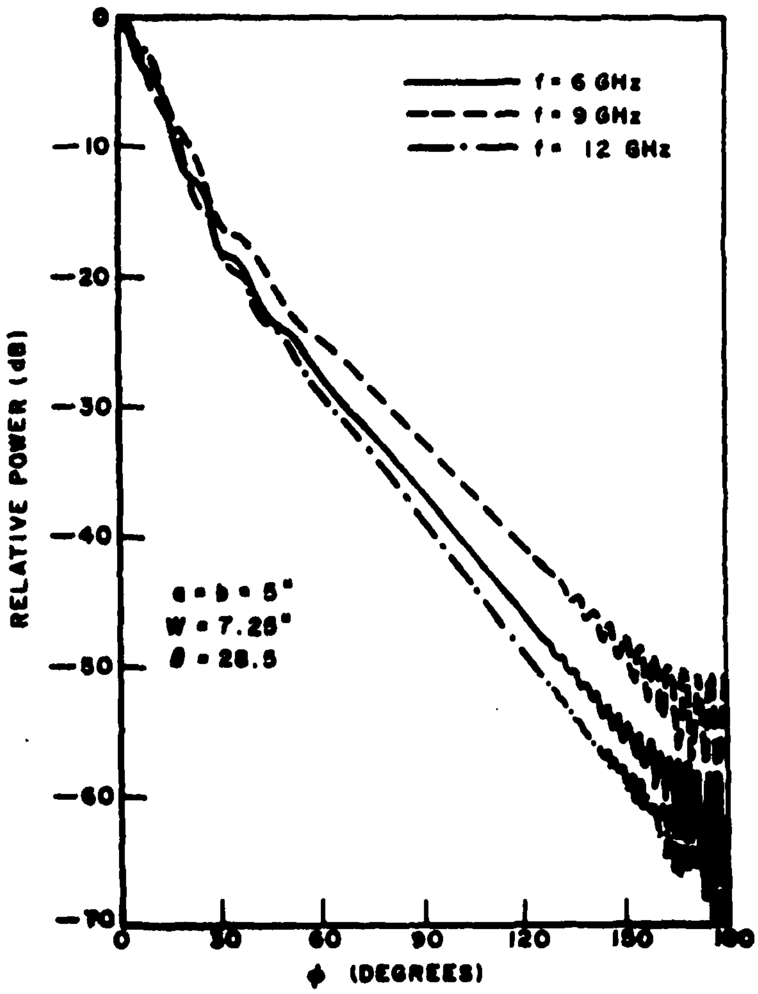

Figure B-6. Calculated E-plane patterns of "aperture-matched" horn versus frequency.

is only one of two significant terms making up the normal horn impedance, the throat reflection, now, remains as the dominant contributor. Using the procedure suggested by Terzuoli, et al., [3], one can also reduce the throat reflection by adding a throat matching section as shown in Figure B-7. Note that the curved section in the throat forms a smooth transition between the waveguide and horn walls. Such a throat section is available on a NARDA* standard gain horn. Using the NARDA horn, its impedance was measured across X-band, and the results are shown in Figure B-7. In that the throat reflection is negligible compared to the aperture reflection, one obtains a relatively small VSWR across the frequency band. On the same figure, the horn impedance is shown with small circular cylinder sections added to the NARDA horn.

It is very apparent from these results that the "aperture-matched" horn with a modified throat has superior impedance performance compared

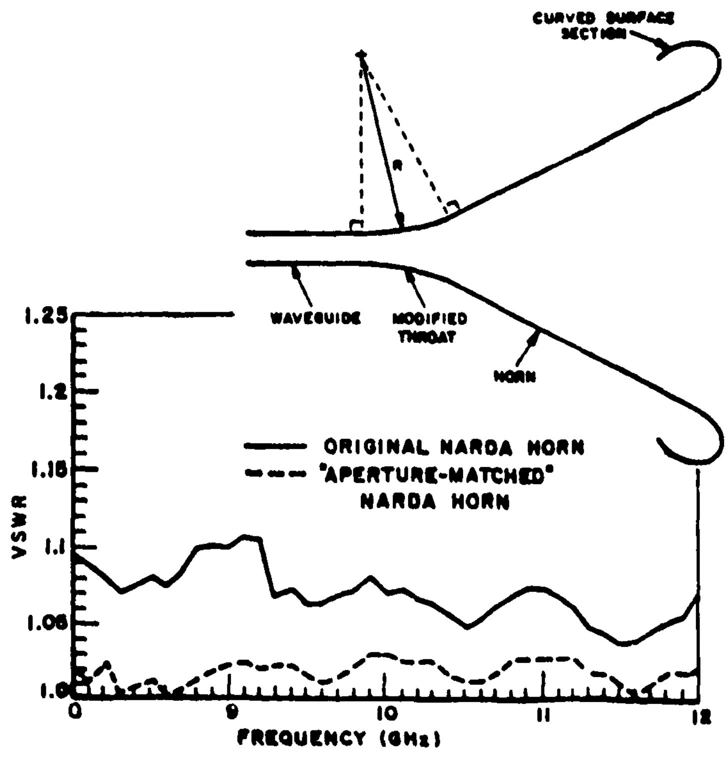

Figure B-7. Measured VSWR for various horns.

to either a conventional horn or one with a modified throat section. In addition, it is felt that an even greater bandwidth than shown in Figure B-7 can be achieved using a ridged waveguide to feed the horn.

Publications

1. C.W. Chuang and W.D. Burnside, "A Diffraction Coefficient for a Cylindrically Truncated Planar Surface," IEEE Trans. on Antennas and Propagation, Vol. AP-28, pp. 177-182, March 1980. Also an oral paper presented at IEEE AP-S Symposium in Seattle, June 1979.

2. W.D. Burnside and C.W. Chuang, "An Aperture-Matched Horn Design," has been accepted for publication in IEEE Trans. on Antennas and Propagation. Also an oral paper presented at IEEE AP-S Symposium in Quebec, June 1980.

3. W.D. Burnside and C.W. Chuang, "Diffraction from Cylindrically Truncated Planar Surfaces with Application to an Aperture-Matched Horn Design," to be presented at IEE Antennas and Propagation Symposium in London, April 1981.

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C. Antenna Studies

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Dr. D.M. Pozar, Research Associate
P. Tulyathan, Graduate Research Associate

Accomplishments

1. Objectives and Background

The purpose of our research is to develop general purpose low-frequency (i.e., applicable to structures not large in terms of a wavelength) computer techniques for designing and analyzing antennas, including effects of their support structure(s). This is being done by developing a general purpose computer code using moment-method, surface-patch modeling for analyzing composite wire and plate geometries [1,2]. The work here centers on the development of basic computational techniques, rather than their implementation into a general purpose code. The plates can be interconnected to model the support structure, i.e., a ship, a building, an airplane, etc., and the wires are used to model antennas, masts, etc.

At present, an efficient user-oriented computer code is available which can treat the following:

(1) thin wires
(2) rectangular plates
(3) plate-to-plate intersections
(4) wire-to-plate intersections
(5) open or closed surfaces

The code can compute currents, impedance, efficiency, far-zone radiation patterns, and radar cross-section (back or bistatic scattering). Probably the two major factors limiting the generality of the code are (1) wire-to-plate junctions must be at least 0.1λ from an edge, and (2) plates must be rectangular, i.e., cannot treat polygon plates. The past year's effort has been to perform the basic work to solve these two problems. A brief summary of each is presented below.

2. Wire Attachments Near an Edge

The existing basic code incorporates techniques which allow for a wire to contact a plate, provided that the contact point is 0.1λ or more from the edge of the plate. The attachment is treated by using an "attachment mode" which

(1) enforces continuity of current at the wire/plate junction
(2) enforces the $\hat{\rho}/\rho$ singularity of the surface current density in the vicinity of the attachment point
(3) enforces current spreading uniformly from the attachment point

When the attachment point is near an edge, (1) and (2) above need to be enforced, but not (3). That is, the current does not spread uniformly from an attachment point near an edge.

Previously, the problem of a wire attached near the edge of a half-plane edge was considered [3,4]. This year's work considered wires attached near a wedge of arbitrary angle or near a corner. The solution to this problem involves constructing an attachment mode which enforces (1) and (2) above. In addition, the mode enforces the proper non-uniform spreading of the surface current density, which is a function of the wedge angle and the distance of the attachment point to the edge. The attachment mode can also enforce continuity of current around the edge of the wedge. Finally, all this must be done in a computationally efficient manner. Details of the solution have been submitted for publication [5].

Some sample calculations based on this work will now be presented. Figure C-1 shows the input impedance of an $\lambda/4$ monopole versus its distance to a 90^0 wedge. The surface-patch moment method results and measured results are for the 90^0 wedge formed by two $.4\lambda$ square plates. The eigenfunction solution is for an infinite 90^0 wedge. Figure C-2 shows the input impedance of a $\lambda/4$ monopole versus its distance to a three-plate 90^0 corner or vertex. The solution is in good agreement with measurements.

3. Non-Rectangular Plates

In modelling a support structure using the present moment method surface-patch code, one arranges several interconnected (and/or unconnected) rectangular plates to approximate the structure. While many structures can be approximated by rectangular plates, the generality and efficiency of the method would be improved if one could use non-rectangular or polygon plates. For example, the bow of a ship may be modelled by a triangular plate. The swept wings on aircraft or the fins on missiles can be modelled by a quadrilateral plate.

The modelling of rectangular plates is considerably simplified by the fact that rectangular surface-patch modes nicely "fit" the rectangular plate. For a general polygon plate, it is not clear that there is a single mode shape which nicely "fits". Thus, probably the most important problem in developing a surface-patch moment-method solution for polygon plates is to develop a technique for fitting non-rectangular modes to the polygon plate.

The technique should have the following characteristics:

(1) modes with components in orthogonal directions at each point on the plate;
(2) for a given maximum mode size, as few modes as possible should be required to cover the plate;

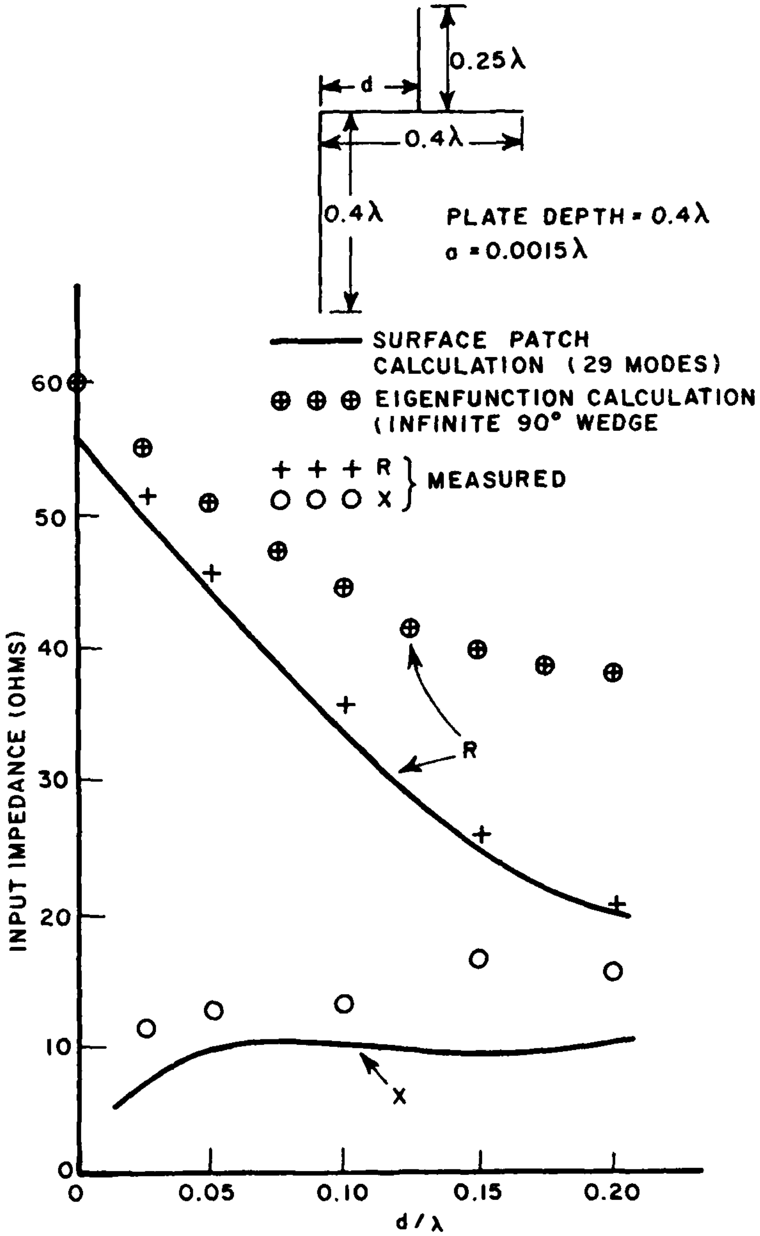

Figure C-1. Input impedance of $\lambda/4$ monopole on a 90^0 wedge versus d. Wire radius a = .0015λ.

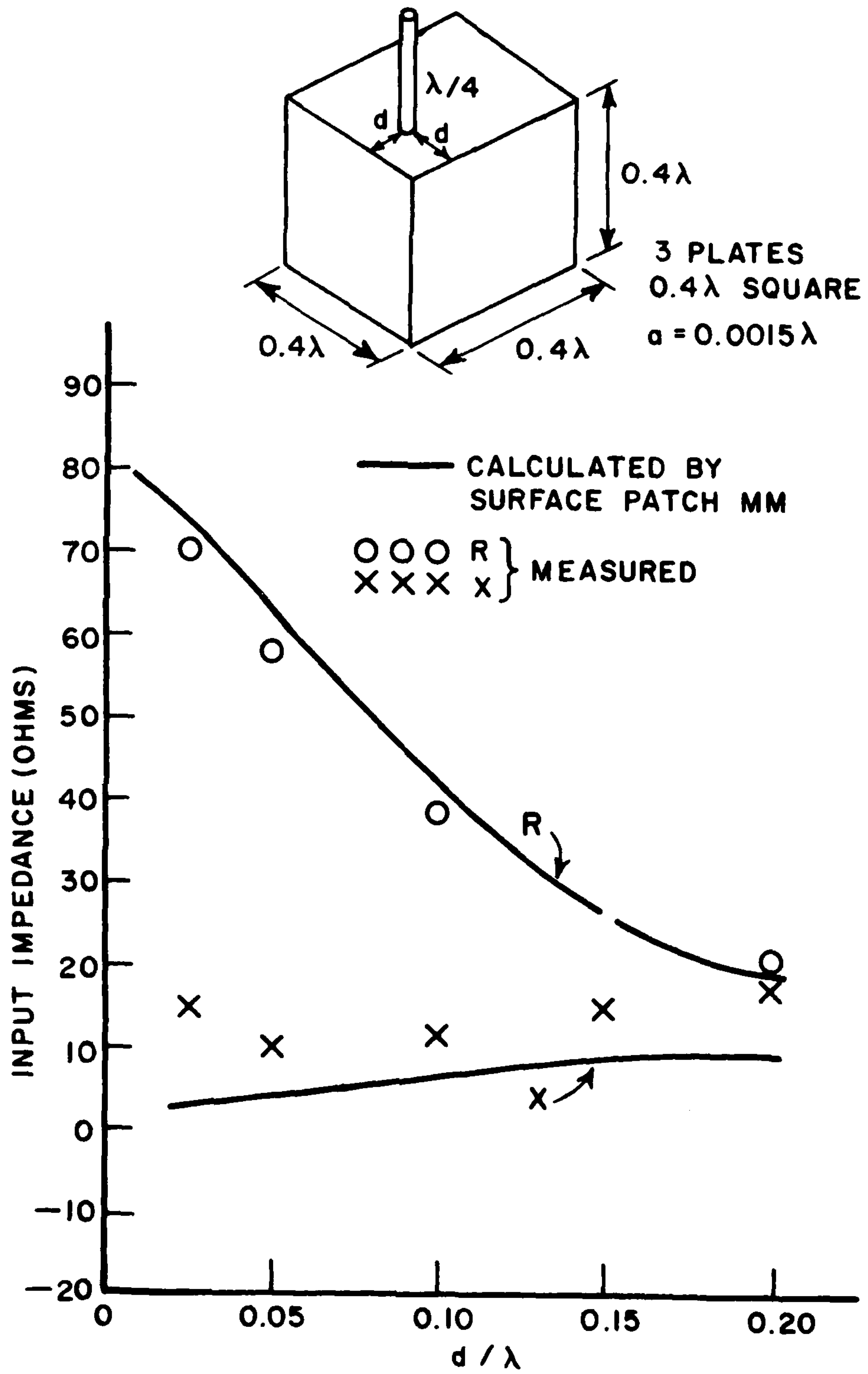

Figure C-2. Input impedance of a λ/4 monopole near a corner of three .4λ square plates. (Vertex angles = 90°) Wire radius a = .0015λ.

(3) the technique should be suitable for machine automation; any technique which requires the code user to determine the mode layout on a complex polygon would be almost useless;

(4) the technique should be suitable for efficient implementation in a general purpose code.

We have investigated three methods for placing modes on a polygon plate. The details of the segmentation process will not be discussed here, but rather we will present some results. Figure C-3 shows the mode layout for one polarization on a polygon plate. Figure C-4 shows the input impedance of a monopole in the center of a polygon plate. Figure C-5 shows the radar cross-section of a plate similar to an airplane tail fin.

Publications and References

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[2] E.H. Newman and D.M. Pozar, "Considerations for Efficient Wire/Surface Modelling," IEEE Trans. on Antennas and Propagation, Vol. AP-28, No. 1, January 1980, pp. 121-125.

[3] D.M. Pozar and E.H. Newman, "Near Fields of a Vector Electric Line Source Near the Edge of a Wedge," Radio Science, Vol. 14, No. 3, May/June 1979.

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[5] D.M. Pozar and E.H. Newman, "Analysis of a Monopole Near an Edge or a Vertex," submitted for publication, IEEE Trans. on Antennas and Propagation.

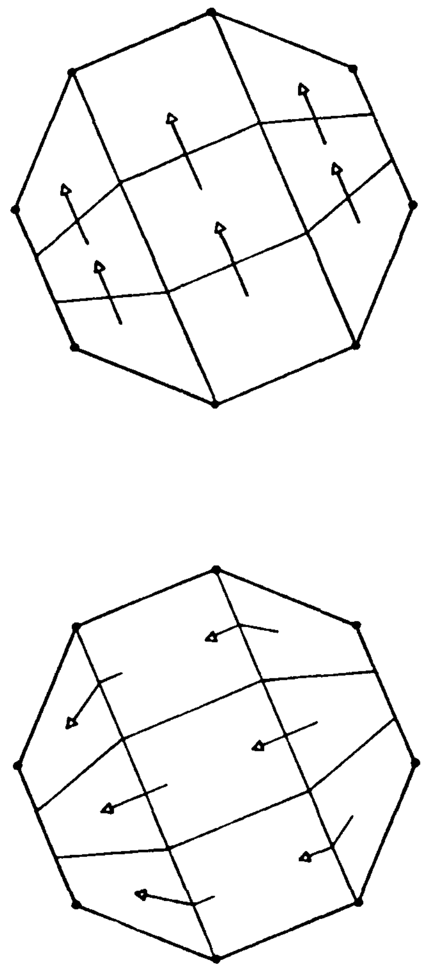

Figure C-3. Surface patch dipole modes generated by Method 1 for a regular octagon.

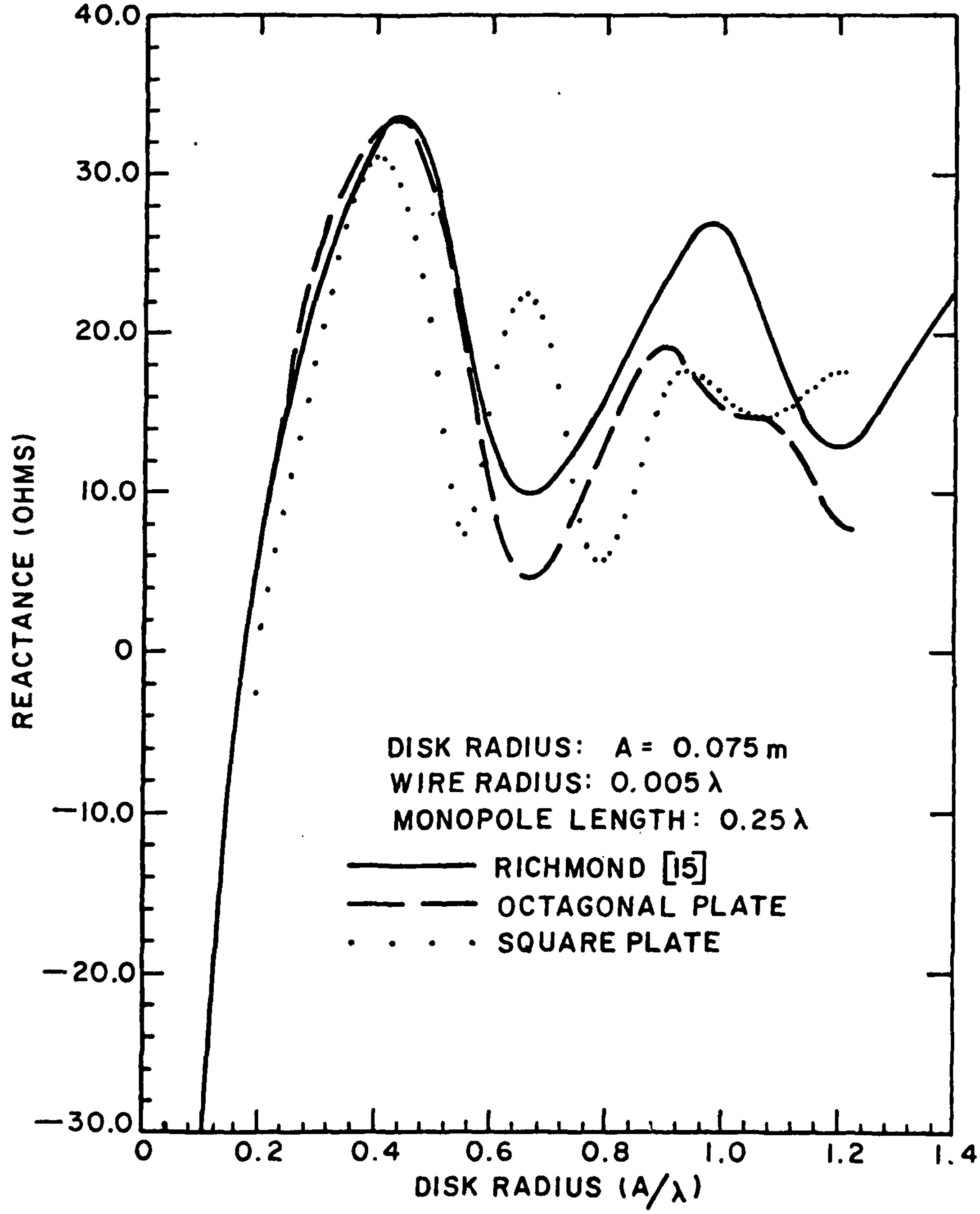

Figure C-4 a. Reactance of a monopole antenna at the center of a disk in free space.

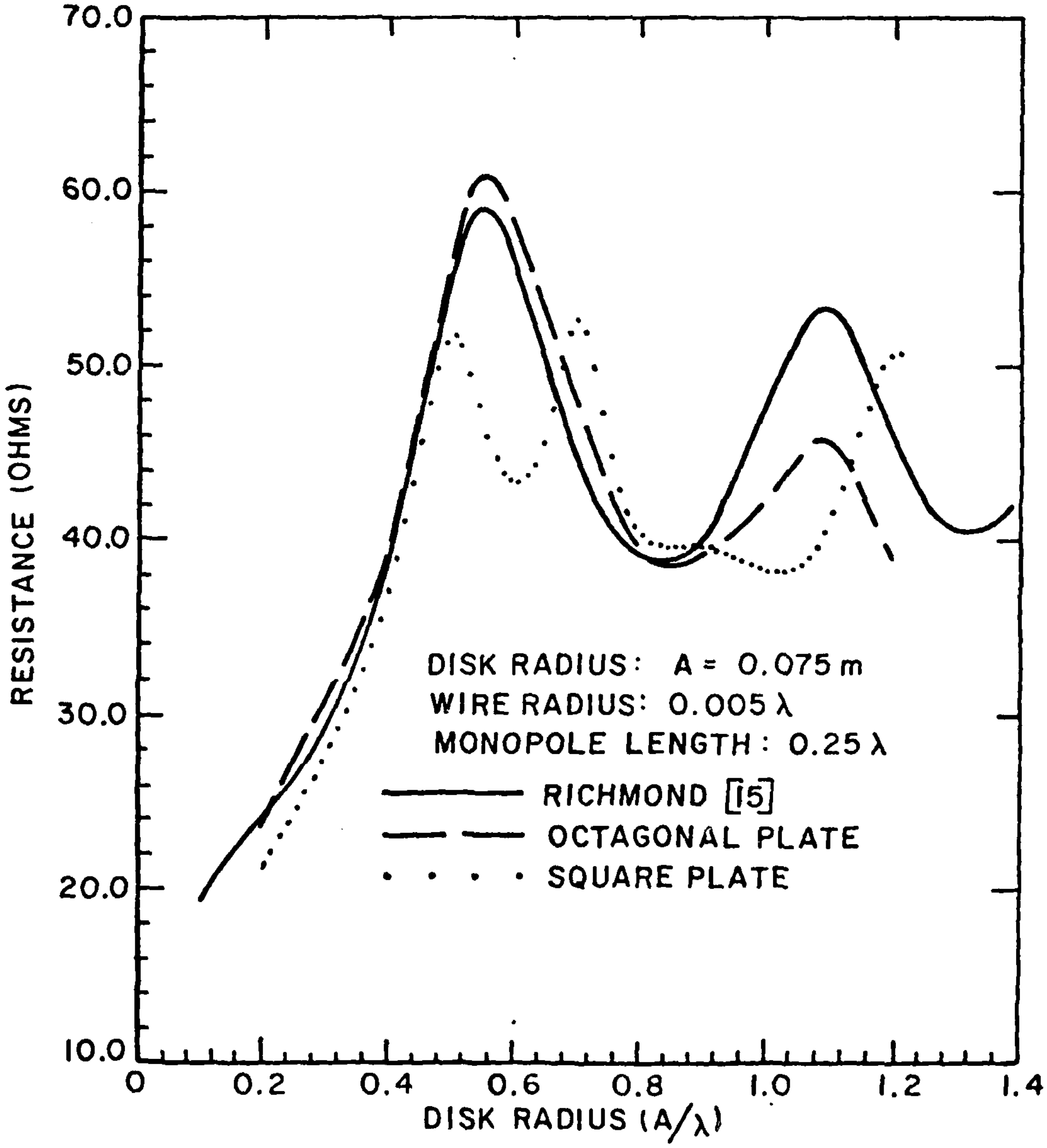

Figure C-4 b. Resistance of a monopole antenna at the center of a disk in free space.

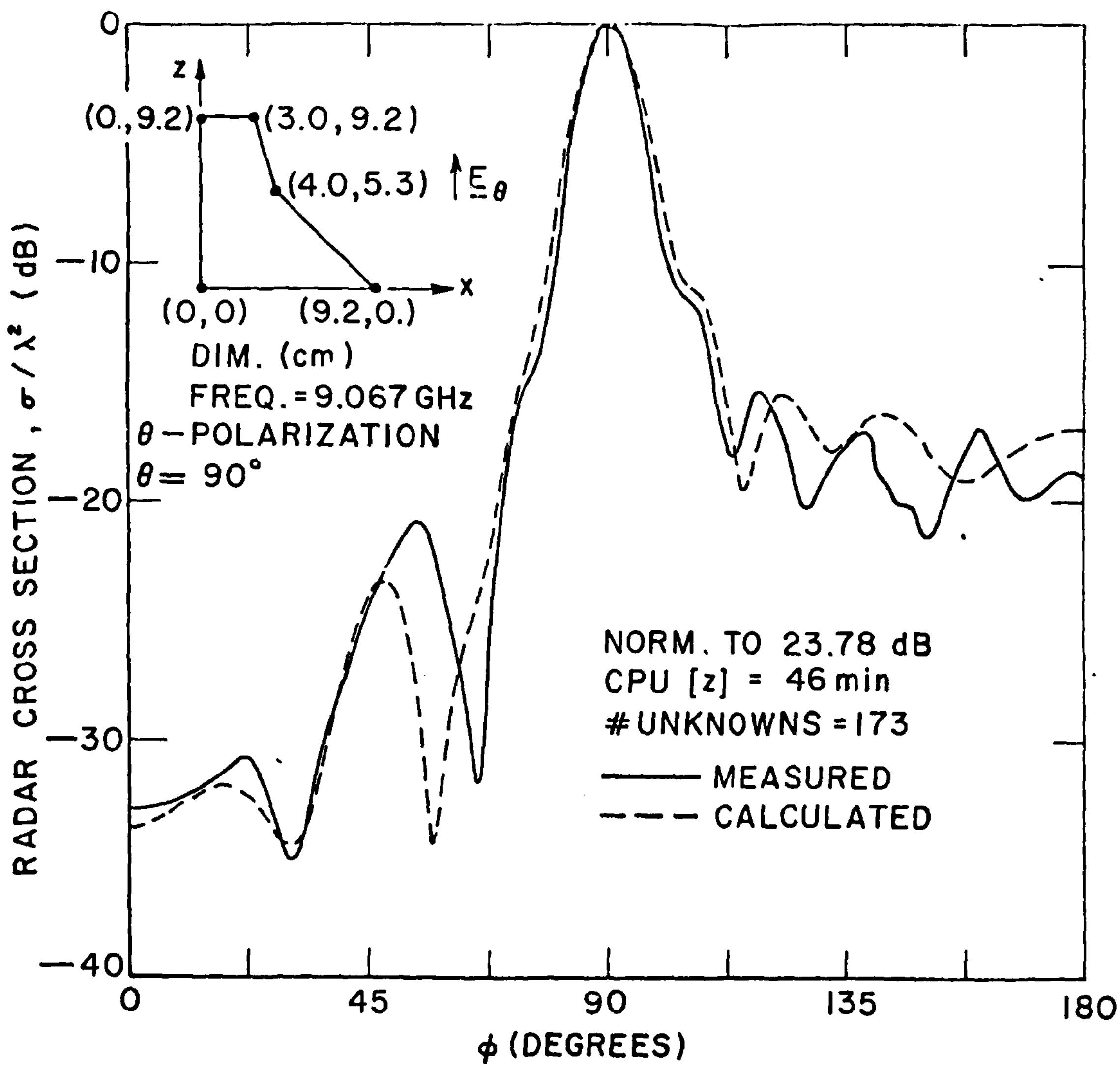

Figure C-5. Backscatter from a five-sided plate with a 3λ nominal size (θ-polarization).

D. Time Domain Studies

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L.C. Chan, Graduate Research Associate

C.M. Rhoads, Graduate Research Associate

Accomplishments

1. Background

Application of time domain concepts and methods to radiation and scattering problems (vector and scalar) yields tremendous diagnostic and interpretive insight. The exploitation of this insight for improved detection and cognition of a signal or signals is the coagulant of our research. The general goals of this research include:

(1) prediction of scattered and radiated waveforms for objects of increasing geometric complexity for point or plane wave sources with arbitrary waveforms,

(2) investigation of target-dependent excitation waveforms and/or signal processing algorithms to identify and optimize response from specific targets, and

(3) determination of the effects of signal bandwidth and noise on recommended techniques for detection and identification of radar targets or more general targets in remote sensing.

Progress toward these goals is summarized in the following sections. This section concludes with a brief discussion of papers and reports published, submitted for publication, or in preparation.

Two invited papers have been written for a forthcoming special issue of the IEEE Transactions on Antennas and Propagation on Inverse Scattering. The invited papers are:

"Transient Response Characteristics in Identification and Imaging," D.L. Moffatt, J.D. Young, and A.A. Ksienski.

"An Improved Electromagnetic Subsurface Radar Using Antenna Design Concepts," L.C. Chan, L. Peters, Jr., and D.L. Moffatt.

These invited papers are, in part, a combination of publications numbered 9, 10, 11, 13, and 15 as given in [1]. This consolidation was made at the request of the editor for the special issue. In addition to other related research at the ElectroScience Laboratory (ESL), the first invited paper covers our general philosophy of radar target identification via complex natural resonances, extraction of these resonances or a difference equation from noisy transient signals using eigenanalysis, and the application of these concepts and methods to identification of naval vessels and aerospace vehicles using real measured data. The second invited paper basically covers systems aspects of these same ideas applied to a subsurface radar for the identification of shallow buried targets. Other aspects of the subsurface radar and complex natural resonances have been published in another special issue [2] and as a chapter in a book [3].

Three additional papers,

"The K-Pulse Concept," E.M. Kennaugh,

"Radar Imagery Spectral Content," D.L. Moffatt, and

"Subsurface Radar Target Imaging Estimates," L.C. Chan, D.L. Moffatt, and L. Peters, Jr.

have been written for this same special issue. In addition, Professor Emeritus E.M. Kennaugh has written an invited page of introductory remarks for the issue. The K-Pulse concept was discussed in [4], where examples of the K-Pulse response of a finite thin wire were given. Since the K-Pulse elicits a response waveform, monoscillatory, of minimal duration, it necessarily encompasses most of what can be exploited using the complex natural resonances of an object. Additional examples of the K-Pulse for lossless and lossy uniform transmission lines are given in the special issue paper.

The second special issue paper discusses the spectral range of scattered field data necessary to produce an isometric three-dimensional image of a radar target. To this end a relationship between the cross-sectional area of the target along the line of sight and the scattered field predicted by the physical optics approximation (first presented by Eberle [5] and attributed to Kennaugh) is rederived in the time domain. It is then demonstrated that for numerous classes of object shapes such an approximation can be extended beyond very short times and yields much more than specular information. With this approach, images are produced using low frequency data [6] at a few aspects. The fact that low frequency data are used to produce the target image based on a high frequency approximation interpretation requires careful Fourier considerations for acceptance.

2. Natural Resonances and Surface Waves

The K-Pulse concept provides a means of relating surface waves on the object to the complex natural resonances of the object. An example for a conducting spherical object was given in [4] and is extended to prolate spheroids in the special issue paper. These results were obtained using geometrical theory of diffraction (GTD) estimates of the surface waves. For general finite wire geometries (curved, bent, intersecting, etc.) simple estimates of the frequency-dependent reflection, transmission, and distortion coefficients for surface waves on the wire are necessary to extend the theory and apply flow graph derived characteristic equations. To obtain these coefficients various approximate analytical theories are being compared to quasi-exact numerical computations. Combined with a similar treatment of finite flat surfaces, such approximate surface wave expressions will be used to obtain complex natural resonances of simple target structures [1].

3. Cavity-Type Structures

Over significant spectral and aspect regions, the radar cross-sections of modern aricraft are dominated by returns from the jet engine intake and exhaust cavities. The modulation of radar signals by the engine rotors is one approach to identification of the aircraft. Interest here, however, is in the complex natural resonances of such structures. As a preliminary step, the backscattered fields for axial incidence on finite, hollow, circular cylinders (shorted and open at the rear), a circular disk, a circular loop, and a semi-infinite circular waveguide* are being compared. One such comparison (normalized radar cross-section) is shown in Figure D-1. Only a few points are shown for the waveguide, the normalized cross-section of this structure approaches unity for high frequencies. At frequencies below cutoff for the first propagating mode in the cylinders (TE_{11}), the finite cylinders are nearly identical and their average radar cross-section similar to that of the disk and the semi-infinite waveguide. Ramp response waveforms for the disk (Figure D-2a) and the open (Figure D-2b) and shorted (Figure D-2c) finite cylinders are shown in Figure D-2. For the cylinders in Figure D-2b and D-2c note that the effect of an open or short termination at the rear is only evident after a significant delay time (energy velocity of the propagating modes in the cylinders). The damped ringing of the leading portion of the cylinder returns is associated with the rim or front aperture resonances and is, therefore, identical for both cylinders and exactly the same as for a semi-infinite cylinder. The slight magnitude difference in the finite cylinder returns in Figure D-2 is because the fundamental frequency used to synthesize the waveforms is slightly too high for the shorted cylinder (Figure D-2c has not damped to zero in the period of the fundamental). The second distinct ringing in the cylinder returns is due to waveguide modes propagating the length of the cylinder, reflecting at the rear, again propagating the length of the cylinder and radiating at the front rim. In these waveforms the large positive jump at $t = 2L/c$ is from surface waves traveling on the outer surface of the cylinder and diffracting across the rear rim. Complex natural resonances for finite hollow cylinders, a disk, a loop, and a semi-infinite waveguide are currently being extracted from waveforms similar to those in Figure D-2 using the eigenanalysis method.

*The waveguide work is an unfunded dissertation study, but of sufficient interest that a report of the study will be published on this program.

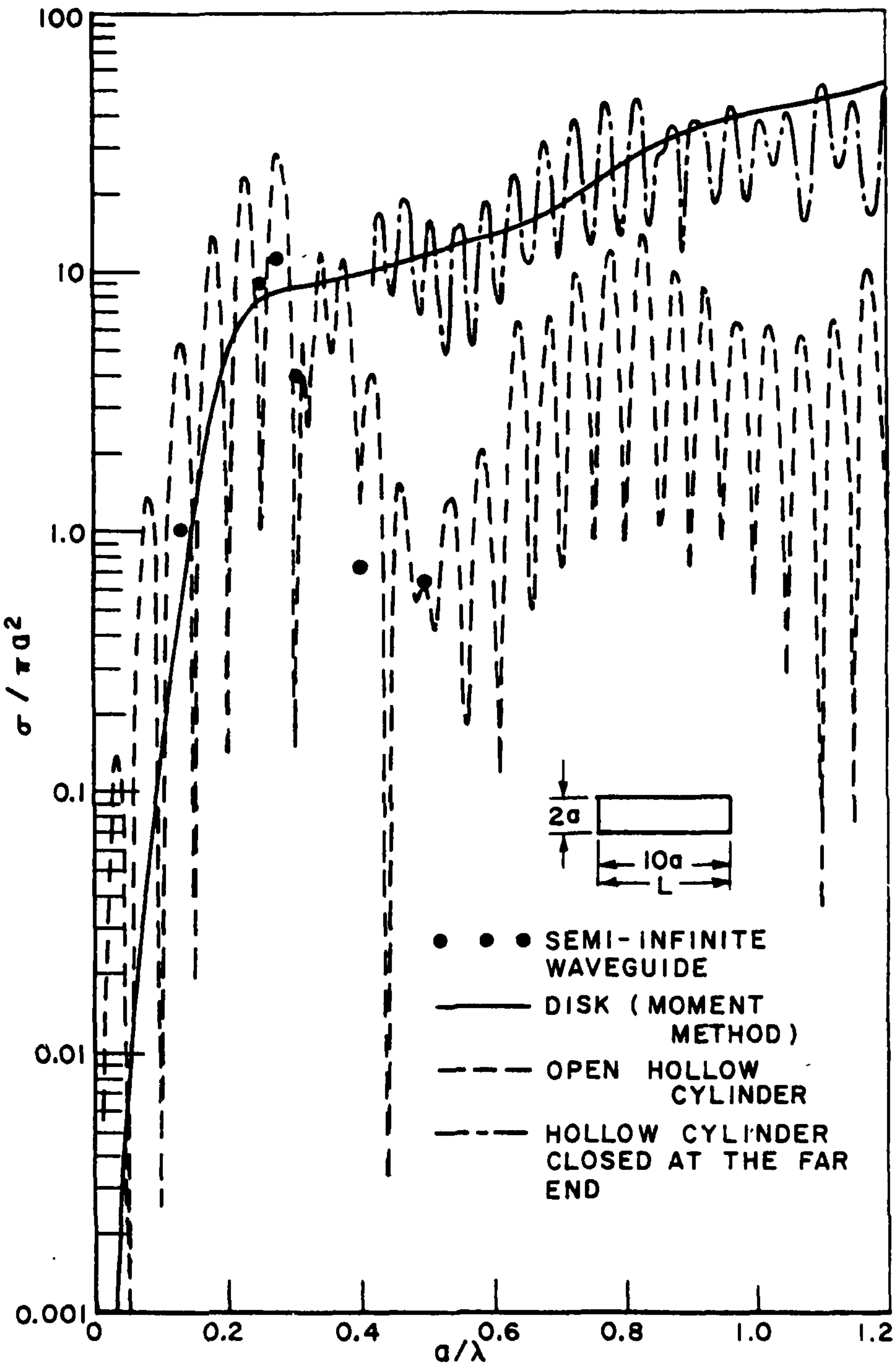
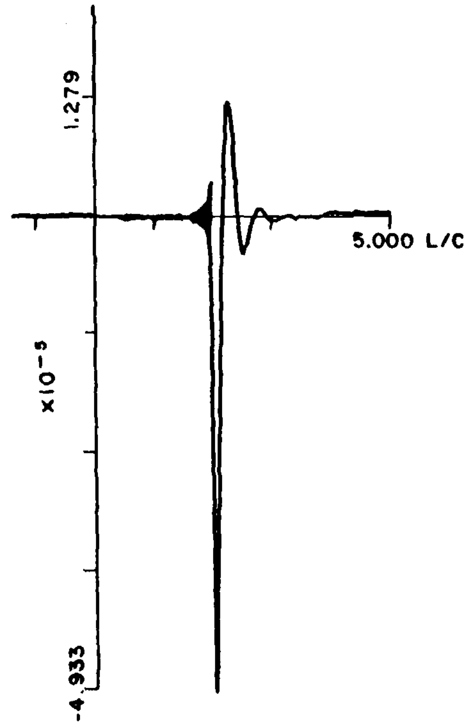
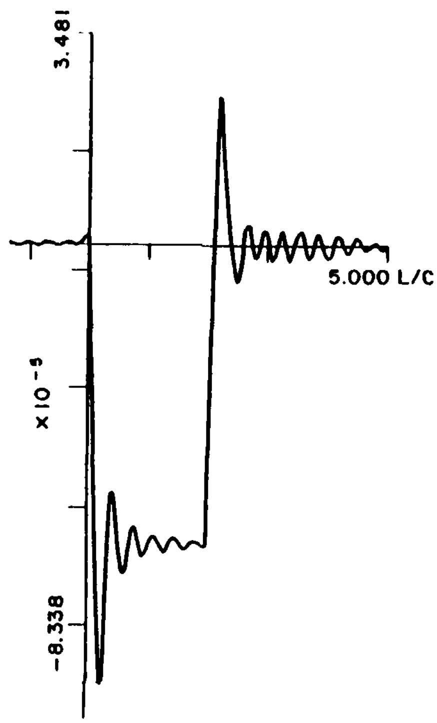


Figure D-1. Normalized axial radar cross-sections of finite hollow cylinders (open and shorted at far end), a circular disk, and a semi-infinite circular waveguide.



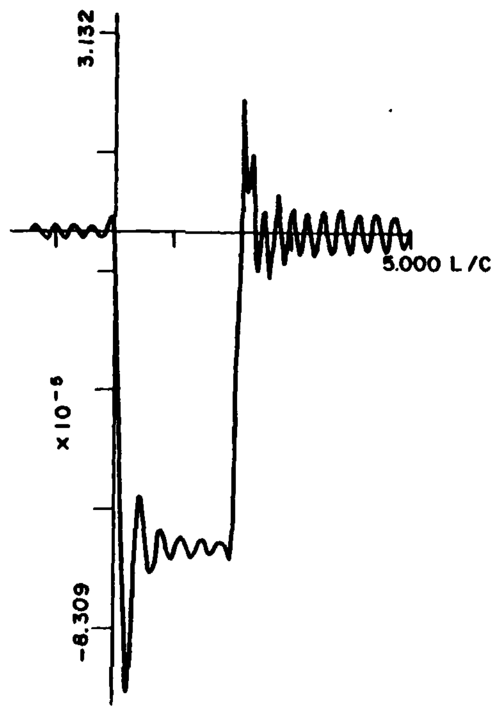
2a. Axial ramp response of circular disk (disk a distance L from origin).

Figure D-2. Ramp response waveforms for axial incidence.



2b. Axial ramp response of hollow cylinder open at both ends.

Figure D-2 continued.



2c. Axial ramp response of hollow cylinder shorted at far end.

Figure D-2 continued.

4. Difference Equations and Eigenanalysis

A detailed discussion of finite exponential sum approximations of transient signals, Prony's method, equivalent difference equations and least-squared-error solutions using eigenanalysis was given in [4] and is updated in the first invited paper discussed above. The following sentences summarize our conclusions with regard to this work. Approximating a transient signal by a finite sum of exponentials is equivalent to finding a homogenous difference equation for the signal. If total squared error is the criterion, then (for an Nth order difference equation) of the N+2 possible solutions for the difference coefficients the minimum possible total squared error is obtained using eigenanalysis, which bounds the norm of the coefficients but does not prejudice the relative magnitude of any coefficient.

A sampling rate for the signal slightly greater than the Nyquist rate is best and at least twice as many equations as unknowns should be used. While the sampling rate for each data entry in the data matrix [4] must be constant, the sample rate for each column is essentially arbitrary. This affords tremendous flexibility in generating the data matrix. Furthermore, row entries for the data matrix can be taken from more than one transient signal from the same target. Therefore, it is possible to obtain one difference equation for a target from transient signals at various aspects or locations.

Averaging several pole sets obtained from each transient signal [3] is no longer necessary. With noiseless data, all of the N+2 least-squared-error methods are equivalent. With noisy data, however, the eigenanalysis method always yields the minimum squared error. All of the methods are noise sensitive with the actual noise-to-signal level required to successfully extract the resonances from the signal dependent on the damping rate of the dominant resonances. Excluding such high Q structures as thin wires, an overall noise-to-signal of less than -20 dB seems generally necessary even with some averaging of the signals.

It is concluded that, in general, the difference equation or natural resonances of a target should be obtained using data measured in a controlled environment, e.g., from model scattering measurements. Subsurface radar applications are an exception [2,3] and show that actual field data can be successfully processed in some cases.

5. The K-Pulse

The concepts and applications of the K-Pulse were given in [4] and briefly summarized again in [1]. The special issue paper by E.M. Kennaugh gives additional examples for prolate spheroids and for shorted uniform transmission lines. Because the K-Pulse can be related to one or more surface waves on an object and is, therefore, simply related to the complex natural resonances of the object, it is, directly or indirectly, pertinent to much of the research in this work unit.

Publications and Presentations

1. Papers

L.C. Chan, D.L. Moffatt, and L. Peters, Jr., "Characterization of Subsurface Radar Targets," IEEE Proceedings, Special Issue on Subsurface Electromagnetics, July 1979.

D.L. Moffatt and C.M. Rhoads, "Radar Identification of Naval Vessels," accepted for publication as correspondence, IEEE Transactions on Aerospace and Electronic Systems.

L.C. Chan, L. Peters, and D.L. Moffatt, "Improved Performance of a Subsurface Target Identification System Via Antenna Design," invited paper accepted for publication in a Special Issue of IEEE Trans. on Antennas and Propagation on Inverse Scattering and Related Topics.

L.C. Chan, D.L. Moffatt, and L. Peters, Jr., "Subsurface Radar Target Imaging Estimates," accepted for publication in a Special Issue of IEEE Trans. on Antennas and Propagation on Inverse Scattering and Related Topics.

D.L. Moffatt, "Radar Imagery Spectral Content," accepted for publication in a Special Issue of IEEE Trans. on Antennas and Propagation on Inverse Scattering and Related Topics.

D.L. Moffatt, J.D. Young, and A.A. Ksienski, "Transient Response Characteristics in Identification and Imaging," invited paper accepted for publication in IEEE Trans. on Antennas and Propagation, Special Issue on Inverse Scattering.

E.M. Kennaugh, "The K-Pulse Concept," accepted for publication in IEEE Trans. on Antennas and Propagation, Special Issue on Inverse Scattering.

D.B. Hodge, "Scattering by Circular Metallic Disks," accepted for publication in IEEE Trans. on Antennas and Propagation.

2. Book Chapter

L.C. Chan, D.L. Moffatt, and L. Peters, Jr., "Estimation of the Natural Resonances of a Class of Submerged Targets," in Acoustic, Electromagnetic and Elastic Wave Scattering - Focus on the T-matrix Approach, Pergamon Press, 1980.

3. Oral Presentations

D.L. Moffatt, "A Chronological History of Radar Target Imagery at The Ohio State University," IEEE AP-S/URSI Joint Symposium, Seattle, Washington, June 1979.

D.L. Moffatt and C.M. Rhoads, "An Update on Naval Vessel Identification," IEEE AP-S/URSI Joint Symposium, Seattle, Washington, June 1979.

D.L. Moffatt and K.A. Shubert, "Pulse Response Waveforms of Aircraft," IEEE AP-S/URSI Joint Symposium, Seattle, Washington, June 1979.

E.M. Kennaugh, "Prediction of Cavity and Natural Resonance Frequencies by GTD," IEEE AP-S/URSI Joint Symposium, Quebec, Canada, June 1980.

4. Reports

D.B. Hodge, "The Calculation of Far Field Scattering by a Circular Metallic Disk," Report 710816-2, February 1979.

Mithouard, D.P. and D.B. Hodge, "Electromagnetic Scattering by a Metallic Disk," Report 710816-3, September 1979.

T.W. Johnson and D.L. Moffatt, "Electromagnetic Scattering by Open Circular Wave Guides," Report 710816-9, December 1980, The Ohio State University ElectroScience Laboratory, Department of Engineering.

5. Theses and Dissertations

C.M. Rhoads, "The Identification of Naval Vessels Via an Active, Multi-frequency Radar System," Master of Science Thesis, The Ohio State University, 1979. (This work was supported, in part, by Joint Services Electronics Program Contract N00014-78-C-0049 with Office of Naval Research; and Contract N00014-76-C-1079 with Office of Naval Research.)

L.C. Chan, "Subsurface Electromagnetic Target Characterization and Identification," Ph.D. Dissertation, The Ohio State University,

1979. (This work was supported, in part, by Grant ENG76-04344 with National Science Foundation; Contract DAAK-77-C-0174 with U.S. Army Mobility Equipment Research and Development Command; and Joint Services Electronics Program Contract N00014-78-C-0049 with Office of Naval Research).

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E. Adaptive Array Studies

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Kah-Jeng Suen, Graduate Research Associate

Accomplishments

During the past year, JSEP funds have been used to support adaptive array studies in four areas:

(1) the effects of multiplier saturation in the improved LMS loop,
(2) the effects of array and signal parameters on the eigenvalues of the covariance matrix,
(3) the effects of element patterns and signal polarization on array performance, and
(4) the effects of differential time delays on the performance of the LMS loop.

Each of these areas is discussed below.

1. The Effects of Multiplier Saturation in the Improved LMS Loop

The LMS feedback loop has the property that its time constants vary with signal power. This situation causes a dynamic range problem in an adaptive array because most adaptive array applications require the time constants to stay within certain bounds. During the previous two JSEP contract periods, the problem of time constant variation in the continuous LMS loop was addressed. An improved form of the LMS loop was developed [1] that appears to solve this problem. During the last contract period, study of the effects of multiplier saturation in this new loop was initiated but not completed. During the current contract period, this study has been completed.

The improved LMS loop contains two correlation multipliers, instead of one as in the original LMS loop. The theoretical development of this loop assumes these multipliers to be ideal. In practice, of course, multipliers are subject to saturation and other defects. With ideal multipliers, the improved loop has time constants that do not vary with signal power. The purpose of this study was to determine how multiplier saturation affects the time constants of the loop. Our results show that saturation will modify the fixed time constant property of the loop. When any of the multipliers saturate, the time constants again depend on signal power. Calculations have been made to determine how fast the time constants become "spread" as the incoming signals drive the multipliers further into saturation. The results of this study will be useful in the experimental work to be carried out in the future under another contract.

2. The Effects of Array and Signal Parameters on the Eigenvalues of the Covariance Matrix

The time constant behavior of the LMS array is dictated by the eigenvalues of the covariance matrix. Although it is well known that these eigenvalues depend on signal powers, arrival angles and bandwidth, as well as array geometry and element patterns, in fact, there appears to be no detailed information in the literature showing how the eigenvalues behave.

For this reason, we have calculated the eigenvalues for several simple arrays as a function of the number of signals, signal arrival angles, powers and bandwidths. The results allow one to determine the time constant spread that will occur and to determine how it varies with signal parameters.

One especially useful result has been obtained from this work. We have discovered a direct relationship between the middle eigenvalue (the next-to-largest eigenvalue) of the covariance matrix and the output signal-to-interference-plus-noise ratio (SINR) of the adaptive array.

Specifically, as some signal parameters vary (e.g., interference arrival angle), the array output SINR and the middle eigenvalue vary in exactly the same way. Knowledge of this relationship is extremely useful in the problem of choosing array element locations and patterns. Previously, it was thought that element locations and patterns had to be chosen not only to obtain good SINR, but also to minimize eigenvalue variation. It turns out that both objectives are satisfied at once. This knowledge saves considerable effort in the array design problem.

The results of this study are currently being prepared as a Master of Science thesis by Mr. Kah-Jeng Suen, and a paper is planned on this subject.

3. The Effects of Element Patterns and Signal Polarization on Array Performance

During the previous contract period, the performance of some simple polarization sensitive adaptive arrays was studied. Two antenna configurations were analyzed; two pairs of crossed dipoles, and three mutually perpendicular dipoles (a "tripole"). Such arrays have the capability to adapt to incoming signal polarization as well as arrival angle. Our purpose was to determine whether array performance is enhanced significantly by adding the polarization flexibility. We found that the performance of such an array is far superior to one not taking advantage of polarization.

During the current contract period, two papers on these arrays have been completed. These papers have been submitted and accepted for publication.

During the current year, we have also extended this work by computing the SINR performance of a tripole with cross-polarized jamming (i.e., two independent jamming signals on orthogonal polarizations from the same direction), and also by computing the SINR performance of a three-tripole array with both a completely polarized jammer and a cross polarized jammer.

The tripole is a very interesting antenna system for two reasons. First, it can distinguish between a desired signal and an interfering signal on the basis of polarization alone. Second, its performance is not influenced by interference bandwidth, unlike most adaptive arrays. We discuss these points below.

Since each dipole in the three-dipole cluster has its center at the same location, there is no interelement phase shift that varies with signal arrival angle, as in a conventional array. Nevertheless, a tripole adaptive array is still able to reject interference and retain the desired signal when the two signals are not from the same direction. It is able to do this because an interference signal and a desired signal from two different directions project different signals into each dipole. Since the tripole can itself protect a desired signal from interference if the two are at different angles when two or more tripoles are used in a larger array, there are no problems with grating nulls, even if the elements are far apart. Thus, excellent resolution can be obtained by spacing the tripoles far apart without causing grating nulls.

The tripole is also interesting because its SINR performance does not suffer if the interference has non-zero bandwidth. With each dipole at the same location, there is no differential time delay between the interference signals reaching the dipoles. Hence, there is no decorrelation between the interference signal in one dipole and that in another. This fact means that one dipole signal can be subtracted from another, to null the interference, with no loss in SINR due to bandwidth. (In a conventional array, the interference signals in two different elements are only partially correlated, due to interelement time delay. This situation makes it impossible to completely cancel the interference by subtracting one element signal from another. As a result, there is a higher residual interference power in the array output and a poorer SINR from the array.) Moreover, it can be shown that as more elements are added to an adaptive array, the SINR performance of the total array never decreases. Thus, the performance of an array having several tripoles with respect to wideband interference is always at least as good as the performance of a single tripole, and this performance is already rather good. Thus, it appears that using co-located, cross-polarized elements in an adaptive array overcomes the problem of interference bandwidth. A paper on this subject is planned in the future.

4. The Effects of Differential Time Delays in the LMS Loop

Several practical effects limit the performance attainable with an LMS array. Three such effects have been described in the literature: multiplier offset voltages [2], reference loop phase shifts [3,4], and bandwidth effects [5,6]. During this contract period, we have examined the effect of a fourth practical limitation, the problem of differential time delays in the LMS loop.

Each loop in an LMS array derives a weight by correlating the signal on that channel of the array with the error signal. Different path lengths around the two sides of the LMS loop cause the two signals reaching the correlator multiplier to arrive with different time delays. This time delay causes two problems: cycling of the weights during weight transients, and a degradation in array performance that depends on signal bandwidth. To obtain acceptable performance from an LMS array, the designer must hold the differential delay to an acceptable amount.

A study was made of a two-element array to calculate the effects of this differential time delay and to determine how much delay is acceptable. The results are presented in a paper that has been submitted and accepted for publication.

Publications

During this contract period, four papers originally written during the previous reporting period were carried through to publication. These are:

R.T. Compton, Jr., "Improved Feedback Loop for Adaptive Arrays," IEEE Transactions on Aerospace and Electronic Systems, AES-16, 2 (March 1980), p. 159.

R.T. Compton, Jr., "Power Optimization in Adaptive Arrays: A Technique for Interference Protection," IEEE Transactions on Antennas and Propagation, AP-28, 1 (January 1980), p. 79.

R.T. Compton, Jr., "Pointing Accuracy and Dynamic Range in a Steered Beam Adaptive Array," IEEE Transactions on Aerospace and Electronic Systems, AES-16, 3 (May 1980), p. 280.

A. Ishide and R.T. Compton, Jr., "On Grating Nulls in Adaptive Arrays," IEEE Transactions on Antennas and Propagation, AP-28, 4 (July 1980), p. 467.

In addition, three new papers have been generated during this contract period:

R.T. Compton, Jr., "On the Performance of a Polarization Sensitive Adaptive Array," accepted for publication in IEEE Transactions on Antennas and Propagation.

R.T. Compton, Jr., "The Tripole Antenna - An Adaptive Array with Full Polarization Flexibility," accepted for publication in IEEE Transactions on Antennas and Propagation.

R.T. Compton, Jr., "The Effect of Differential Time Delays in the LMS Feedback Loop," accepted for publication in the IEEE Transactions on Aerospace and Electronic Systems.

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F. Supplemental Work Unit - Laser Induced Transients

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D.J. Ryan, Graduate Research Associate

Accomplishments

The present interest in the time domain behavior of antennas and scatterers has been, for the most part, theoretical and computational in nature. One reason for the scarcity of experimental data has been the difficulty in producing an impulsive current source; that is, in realizing the experimental equivalent of a Green's Function Generator. Recent work at the ElectroScience Laboratory [1,2] has led to the development of an appropriate impulsive source. In its simplest form, an optical pulse from a fast rise-time laser is focused on a metallic surface; thermionic emission from the heated surface then constitutes a localized pulse of electric current. The electromagnetic field radiated by this current pulse when the target is one of a number of simple shapes (short post, thin wire, cone) has been measured and used to obtain a rough estimate of the conversion efficiency of the process [1].

Our interest here is to obtain exact relations between the current pulse and the radiated field for some standard geometries, in order to obtain more precise estimates of the conversion efficiency and to illustrate the characteristic time domain signatures radiated by the targets. Our approach to this problem has been through the time domain Green's Function. Of the three canonical geometries (half-plane, cylinder, sphere), the half-plane is the simplest [1]. For example, when a current of moment m(t) is induced at the center of a metal ground plane, the electric field along the ground plane at range R is

$$E(t) = (2Z_0/4\pi R) \left[\frac{1}{c}\ \frac{d}{dt'} + \frac{1}{R} + \frac{c}{R^2} \int_{-\infty}^{t'} \right] \qquad m(t), \qquad (1)$$

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where $Z_o = 120\pi\Omega$, c = velocity of light, and the operator is evaluated at the retarded time t' = t-R/c. The Green's Function is obtained when $m(t) = \delta(t)$. The case of the infinite cylinder is not considered here, because the geometry is not a suitable one for experimental verification. The finite cylinder has been discussed by Demarest and Richmond [3].

In the work reported here, major effort has been devoted to obtaining the Green's Function for the sphere in a form convenient for numerical computation. In the frequency domain, the result is well known [4]. One can obtain the corresponding time domain result by Fourier inversion. Thus, the electric field at distance R in the equatorial plane of a sphere of radius (a) excited at its pole by a current moment $M\,\delta(t)$ is

$$E(t) = -Z_o M/(c^2\tau T) \sum_{n=1,3,5...} B_n \mathcal{F}^{-1} \frac{\left[\omega T h_n^{(1)}(\omega T)\right]'}{\left[\omega\tau h_n^{(1)}(\omega\tau)\right]'} (4\pi i\omega\tau)^{-1} \tag{2}$$

where $\tau = a/c$, $T = R/c$, $B_n = (-1)^{(n+1)/2}(2n+1)!!/(2n)!!$ and $h_n^{(1)}$ is the spherical Hankel function.

Our approach to the inversion is to expand the denominator in partial fractions, so that each conjugate pair of poles has time domain response $\exp(\alpha t)\cos(\omega t+\sigma)$ where $(\alpha+j\omega)\tau$ is a root of $\left[zh_n^{(1)}(z)\right]'$. The numerator then represents a polynomial in (T d/dt) which operates conveniently on the time response of each pole. It is of interest that, term by term, Equation 2 does not satisfy the causality conditions because of the use of the addition theorem in obtaining the frequency domain Green's Function.

Since the sphere is a finite geometry, it is possible to excite it as a target and observe the radiated field (i.e., the time domain signature), and also calculate the total radiated power. Comparison with the calculated signature should then permit an accurate estimate of the moment M for a given laser pulse, and the conversion efficiency. A more detailed account of the work summarized here is given in [5].

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APPENDIX I

PROJECT TITLES AND ABSTRACTS

Project 529081 Improvement of Antennas for Underground Radar (Terrascan)

The objective of this program is to improve the sensing head (antenna) of the Terrascan underground pipe detector developed previously for Columbia Gas and manufactured by Microwave Associates.

Project 784589 Technique for Optical Power Limiting

This is a classified program.

Project 784652 An Advanced Prototype System for Locating and Mapping Underground Obstacles

The objective of this program is to develop a portable video pulse radar system for locating and mapping underground objects to a depth of 10-15 feet. The emphasis is on improving signal processing techniques and optimizing system performance to improve target resolution.

Project 784673 Advanced Numerical Optical Concepts

The objective of this program is the development of the technology for optical computing systems.

Project 784701 A Synergistic Investigation of the Infrared Water Vapor Continuum

This study proposes a thorough 3-year investigation of the water vapor continuum absorption in the 8 μm to 12 μm and in the 3.5 μm to 4.0 μm atmospheric transmission windows. This absorption has been the topic of several previous studies. However, serious questions still remain and the need exists for a definitive study in order to answer questions related to laser radiation propagation through the atmosphere and also for optimization of infrared imaging and sensor systems which depend on 10 μm infrared radiation. The Contractor will use a multiline stabilized CO_2 laser and a spectrophone to perform precision measurements of the absorption by water vapor broadened by nitrogen, oxygen and N_2-O_2 mixtures, over a 17-27° temperature range.

Project 710816 Block Funded Support for Electromagnetic Research

This is research in the area of electromagnetic radiation and scattering including: (1) extension of the Geometric Theory of Diffraction (GTD) for convex surfaces, edges, vertices and time domain solutions; (2) the GTD combined with the Method of Moments (MM); (3) extension of the MM codes utilizing polygon surface current patches and wire/patch attachment modes; (4) transient electromagnetic phenomena including target identification, radar imagery, K-pulse techniques and scattering from a thin, circular disk; and (5) adaptive array studies including dynamic range enhancement, beam pointing accuracy, and effects of element pattern and polarization on adaptive array performance.

Project 710964 Analysis of Airborne Antenna Patterns

The objectives of this program are to: (1) improve the aircraft model for far field pattern computations by considering a more realistic vertical stabilizer; (2) study various ways to model more general antenna types such as a monopole in the presence of directors; (3) examine various flat plate simulation codes; and (4) compare various calculated results with measurements supplied by NASA (Langley).

Project 711353 Extending the Geometrical Theory of Diffraction Using the Moment Method

This is a 3-year basic research program to develop the theory for further extensions of the GTD using the moment method and to implement that theory into computer programs so that the usefulness of the research in various scattering and antenna problems can be demonstrated.

Project 711510 Low Sidelobe Reflector Antenna Study

Far field patterns are to be calculated and compared with the measured patterns provided by AeroSpace Corporation for an available offset reflector and available feed horn. This will provide a verification of the theoretical models and computer codes to be used in developing antenna designs for the desired low sidelobe performance.

Project 711639 Superdirective Arrays

environmental conditions; and (4) make recommendations as to the scheme most likely to satisfy the requirements stated in (1).

Project 712331 Air-to-Ground Measurements, Processing and Analysis of Moving Tactical Ground Targets

An experimental study is proposed of the modulation induced by moving ground vehicles on the returns of a VHF airborne radar. Automatic target and classification procedures developed at the ESL using ground-based data will be extended to data obtained from the airborne radar.

Project 712398 Moment Method Antenna Analysis Techniques

The purpose of this project is to train AeroSpace personnel on the use and operations of Richmond's computer codes.

Project 712527 Research on Near Field Pattern Effects

The objective is to continue present efforts on aircraft antenna computer code development in terms of combining the volumetric pattern analysis for the fuselage with the multiple plate solutions developed earlier. This solution must be efficient and of a form that it can be adopted to the fuselage-wing junction analysis treated previously.

Project 712604 A Meteorological Instrumented Range for Millimeter-Wave Sensors

This project will investigate instrumentation required for air-to-ground millimeter wave sensor performance measurements with emphasis on adverse weather environments.

Project 712661 RCS Studies of Jet Intakes

This project has been separated into two phases: 1) to predict accurately the RCS of jet intakes as a potential tool for aircraft designers; 2) to extend the necessary experiments to be made to confirm the above predictions so that the results would be of value in future target identification studies. These phases can be conducted independently and useful results will be generated by either phase.

Project 712673 The Infrared Spectral Analysis of CF_2Cl_2: Application to Atmospheric Detection and Abundance Measurements for Planned In-Situ Experiments

The objective of this study is the development of computer codes to analyze the performance of a circularly disposed superdirective array with the appropriate feed network.

Project 711679 Jam Resistant Communications Systems Techniques

The objectives of this program include (1) development and testing of a bit-synchronous time-division multiple-access digital communications system suitable for use by a large number of small (airborne) terminals in conjunction with larger ground stations, (2) the application of adaptive arrays for up-link antijam protection of this system, and (3) development of techniques, circuits and components for increased data rates, digital control, and interference rejection in high speed digital communications systems.

Project 711930 Radar Cross Section Studies

The objective is to establish the GTD techniques required to treat the radar cross section of missile and aircraft bodies.

Project 711964 Electrically Small Antennas

This three-year program of research into electrically small antennas has three phases: Phase 1 - a basic study to develop the theory, techniques and computer codes for electrically small antennas mounted on a general structure; Phase 2 - a study to develop the theory, techniques and computer codes for printed circuit antennas; and Phase 3 - a study to compare the K-Pulse concept with more conventional techniques for increasing the maximum data rate in pulse communications using small antennas.

Project 712242 Formulate Quasi-Optical Techniques for Antennas at UHF

The goal of this program is to increase the electromagnetic effectiveness of Navy ships by developing low cost, integrated, systematic EM design procedures.

Project 712257 Application of Optical Computing Techniques to Jet Engine Control

This program involves the following tasks: (1) survey and document control requirements for jet engines using information supplied by sponsor; (2) survey and document the field of optical computing as applied to jet engine controls; (3) generate a report listing the various schemes and comparing them for speed, information processing capability, and ability to withstand the necessary

This is a program of research to study a portion of the infrared spectrum of the molecule CF_2Cl_2. Infrared spectroscopy has proved to be a very sensitive method for detecting the presence of the molecule in the atmosphere, but as yet, little laboratory data exists to aid in determining its atmospheric abundance from in-situ spectra.

Project 712680 Roof-Top Antenna Study

This program will analyze the complex receive voltages in several loop antennas comprising a roof-top direction finding system. Although the exact building and antenna geometry are complicated, the following simplifications will be made: 1) the loop antennas will be modeled by simple rectangular thin wire loops, with one or two feed ports; 2) the roof-top will be modeled by a planar L-shaped perfectly conducting ground plane. The dimensions of the L will be chosen to roughly correspond to the outline of the roof.

Project 712684 Advanced Adaptive Antenna Techniques

Three areas of work are suggested: 1) study the effects of element patterns and signal polarization on the performance of adaptive arrays; 2) study the performance of certain sophisticated jamming techniques against adaptive arrays; and 3) continue work on an adaptive array monograph.

Project 712742 Radar Measurement of Rain Cells

The purpose of this effort is to obtain a statistical characterization of the distribution of rain attenuation along earth-space paths. This is to be accomplished through the simultaneous measurement of path attenuation and radar backscatter. Supporting measurements of the path radiometric temperature and the ground rain rate are also proposed. The resulting data are to be analyzed to yield information which will permit a more accurate conversion of point rain rate statistics to path attenuation statistics.

Project 712754 Research on Fast Semiconductor Infrared Optical Spatial Light Modulators

The following studies will be undertaken: 1) collect data on free-carrier absorption of 10.6 micron light in GaAs as a function of light intensity and wavelength of radiation in the 0.9 micron range; 2) measure free-carrier Faraday rotation as a function of the number of carriers to determine the feasibility of the design; 3) study the feasibility of modulating the absorption of 10.6 micron light in the transition between the heavy and light hole states; 4) design a Numerical Optical Data processor and 5) survey domestic and foreign literature for phenomena that might be useful for optical modulation.

Project 712759 CTS/Comstar Communication Link Characterization Experiment

The angle of arrival and gain degredation of the COMSTAR D-3 beacon will be made until September, 1980. Analysis of the angle of arrival and gain degredation data will then be completed.

Project 712797 Perform Technical Measurement to Determine Whether Discriminants Exist in the Time/Frequency Domain That Will Allow Characterization and Classification of Ground Based Tactical Targets

Experimental measurements of the radar backscatter from a moving tactical ground vehicle will be made. The vehicle will be modified so as to identify the specific source of any induced modulation in the radar return. An experimental plan of operation will be developed and implemented which will allow measurement of the radar return from the tactical vehicle under the conditions imposed by the experiment. The basic radar used will be the transportable VHF, UHF, X-band system developed at this institution.

Project 712798 Derive Basic Understanding of Phenomenology Inherent in EM Scattering Characteristics of Stationary and Moving Tactical Ground Targets

Several types of theoretical studies will be performed with the objective of increasing the understanding of the problem of automatic identification of a tactical ground radar target. The features of interest will include the behavior of the stationary target as a function of frequency, and as a function of polarization. The moving target is quite complex, and the influence of moving substructures on the radar return must be included.

Project 712831 Microwave Oven - Worst Case Probing Analysis

The purpose of this investigation is to use numerical electromagnetic analysis techniques to study the leakage fields of a microwave oven to determine where the strongest fields exist.

Project 712838 **Investigate Bistatic Scattering Characteristics of Moving and Fixed Targets to Determine Whether Discriminants May Exist That Will Allow Target Classification**

The following is proposed: 1) design, build and test a bistatic modification to the present truck-mounted X-band radar system; 2) develop a test plan which will allow the measurement of the bistatic radar return of several tactical ground vehicles; 3) carry out the test plan at an appropriate site, coordinating the site selection and scheduling of the tactical ground vehicles with the appropriate agency; 4) conduct preliminary analysis of the data quality and identify appropriate target identification features of the resulting data; and 5) prepare a final report on this task including results of the data analysis.

Project 712861 **Coal Pile Electromagnetic Sensing Research**

This project involves a research program in electromagnetic subsurface remote sensing as applied to accurate estimation of the quantity of coal in a large coal pile. This problem is important to inventory control at coal fired generating stations in the electric power industry. Coal quantity depends on both density and volume of the pile, and means for remote sensing of both of these parameters is sought.

Project 712875 Feasibility Study of Vehicle Tracking System

ESL will conduct a demonstration to determine the feasibility of an optical tracking system to locate the x and y positions of a point on a moving vehicle with an accuracy $\pm$ 6 inches for both x and y positioning. Both static and dynamic experiments will be designed to demonstrate this resolution capability. The experiments will be carried out on the VDA Pad using a system assembled from equipment currently available at the ESL. The equipment will allow us to demonstrate one dimensional position location with the desired accuracy.

Project 712949 Leaky Ported Coaxial Cable Embedded at a Uniform Depth in a Lossy Half Space

It is the purpose of this research to complete our theory appropriate for a planar interface and the extension of our computer code to obtain numerical results for the associated propagation constants and field configurations.

Project 712978 Antenna Technology Study

Analyze the effect of a multi-layered lossy dielectric planar surface that coats a perfectly reflective surface. Provide computer code which implements this analysis.

Project 713143 Analysis of Airborne Antenna Pattern Distortion Effects

Program to investigate the effects of multiple antennas within a common radome on antenna patterns. Includes the effects of cylindrical radomes, large ground plane associated with fuselages, and other obstacles, i.e., other antennas.

Project 713169 EO Device Signature Reduction

This is a classified program.

Project 713176 Xenon Probe Laser for Atmospheric Studies

The objective is to construct and test a versatile laser, rugged enough for field operation and tunable to various lines in the 2-11.3 μm range, for use as an atmospheric probe laser.

Project 713206 Advanced RCS Reduction

This is a classified program.

Project 713302 Design of Dual Band Antennas

The Navy frequently has need for antennas which will operate at more than one band of frequencies. This project addresses the design of a dual band reflector antenna utilizing a dichroic surface design that is based on extensive experience at the ElectroScience Lab with transparent metallic surfaces.

Project 713303 On-Aircraft Antennas

The objectives of this program are: 1) to develop the capability to analytically synthesize the aperture distribution of a complex antenna array given its free space near field antenna pattern; 2) to test the technique developed in item 1 by using simple antenna arrays; and 3) to investigate the accuracy of the Geometrical Theory of Diffraction as applied to a curved surface in terms of low scattering levels associated with side lobe illumination of such structures.

Project 713319 Measurement of Surface Ship Radar Backscatter at HF for Target Identification Studies

The objective of this program is to develop methods to measure radar backscatter from ships. A computer controlled radar cross section measurement system will be configured for the task of measuring the radar cross section of ship models.

Project 713321 Research on Near Field Pattern Effects

This study consists of the following: 1) develop a near field solution for the volumetric pattern of an antenna mounted on a 3-dimensional fuselage structure; 2) extend the present numerical analysis for near field principal plane patterns to treat multiple plates; 3) using these improved solutions examine their validity and usefulness in analyzing various complex airborne antenna problems; and 4) compare calculated results with measured results.

Project 312616 Development of Radome Construction Technique

This study involves formulating and coding the transmissibility and backscattering for a tripole frequency selective surface.

Project 312657 Study of Frequency Selective Surfaces

This study involves formulating and coding the reflection from a multi-layered frequency selective surface composed of loaded dipoles and dielectric slabs.

APPENDIX II
ELECTROSCIENCE LABORATORY SPONSORING AGENCIES

OHIO STATE UNIVERSITY - ELECTROSCIENCE LABORATORY — ACTIVE PROJECTS DURING OCTOBER 1979 - OCTOBER 1980

PROJECT ENGINEER	PROJECT NUMBER	SPONSOR	CONTRACT OR GRANT NUMBER	STARTING DATE	ENDING DATE	AWARD AMOUNT	SOURCE
	Facilities Contract		AF 33(600)-31168				
YOUNG	529062	Columbia Gas					
YOUNG	529081	Gas Research Inst.	5014-352-0234	06-01-79	05-31-80	59K	
MEADORS	784589	AFSC	F33615-77-C-1011	10-18-76	03-31-81	277K	02
CALDECOTT	784652	EPRI	RP7856-1-3	01-01-77	06-30-81	550K	03
COLLINS	784673	BMD	DASG60-77-0045	03-01-77	09-30-80	249K	02
NORDSTROM/LONG	784701	ARO	DAAG29-77-C-0010	04-01-77	09-30-80	208K	01
WALTER	710816	ONR	N00014-78-C-0049	10-01-77	09-30-80	675K	01
BURNSIDE	710964	NASA/Langley	NSG1498	01-16-78	01-15-81	169K	02
KOUYOUMJIAN	711353	ESD	F19628-78-C-0198	09-01-78	08-31-81	123K	01
RUDDUCK	711510	AeroSpace	P.O. 88318	09-01-78	09-30-80	49K	02
NEWMAN/RICHMOND	711639	NSA	MDA904-79-C-0407	10-24-78	03-05-81	178K	03
KSIENSKI	711679	RADC	F30602-79-C-0068	12-04-78	12-03-81	718K	02
PETERS/BURNSIDE	711930	NASA/Langley	NSG 1613	05-01-79	04-30-81	237K	02
RICHMOND	711964	ARO	DAAG29-79-C-0082	05-01-79	04-30-82	103K	02
MARHEFKA/RUDDUCK	712242	NOSC	N00123-79-C-1469	08-01-79	07-31-82	189K	02
COLLINS	712257	NASA/Lewis	NSG 3302	08-01-79	07-31-81	100K	02
KSIENSKI	712331	Clarkson College	F30602-78-C-0102	08-14-79	02-28-82	35K	02
NEWMAN	712398	AeroSpace	P.O. 10616	09-01-79	08-14-80	14K	05
BURNSIDE	712527	NASC	N00019-80-C-0050	11-29-79	11-28-80	60K	02
LEVIS	712604	Clarkson College	F30602-78-C-0102	01-02-80	12-31-80	47K	02
PATHAK	712661	ESD/Hanscom AFB	F19628-80-C-0056	04-01-80	12-01-81	120K	02
DAMON	712673	NASA/Washington DC	NAGW-31	02-01-80	01-31-81	30K	01
NEWMAN	712680	Southwest Research	P.O. 89694 5W	02-18-80	05-18-80	20K	02
COMPTON	712684	NASC	N00019-80-C-0181	02-11-80	02-10-81	75K	02
MUNK	312616	Lockheed	3WZG6X 3480 A	11-01-79	06-30-80	67K	03
HODGE	712742	Intelsat	Intel-066	03-20-80	10-19-81	158K	01
THURSTON/COLLINS	712754	BMDSC	DASG60-80-C-0037	03-18-80	03-17-81	52K	01
HODGE	712759	NASA	NASW-3393	03-15-80	03-14-81	196K	02
KSIENSKI	712797	Clarkson College	F30602-78-C-0102	03-28-80	12-31-80	47K	02
KSIENSKI	712798	Clarkson College	F30602-78-C-0102	03-28-80	12-31-80	47K	02
NEWMAN	712831	Whirlpool	OSURF MPN 762140	04-15-80	10-15-80	20K	02
KSIENSKI	712838	Clarkson College	F30602-78-C-0102	04-16-80	12-31-80	47K	02
YOUNG	712861	TVA	TVA-53983A	04-17-80	04-16-81	100K	01
SVOBODA/POIRIER	712875	NHTSA	OSU-80-0013	05-08-80	09-08-80	15K	02
GARBACZ	712949	Waterways Exp Stat.	DACA39-80-K-0001	05-01-80	11-30-80	35K	01
RUDDUCK	712978	Lockheed	DB50C6160F	06-09-80	11-30-80	92K	02
MUNK	312657	Ford AeroSpace	SP685911-AA	05-01-80	11-30-80	28K	02
BURNSIDE	713143	SCEEE	F30602-78-C-0148	07-15-80	09-30-80	45K	02
DAMON	713169	ASD, WPAFB	F33615-80-C-1072	08-01-80	02-01-83	100K	01

OHIO STATE UNIVERSITY - ELECTROSCIENCE LABORATORY ACTIVE PROJECTS DURING OCTOBER 1979 - OCTOBER 1980

PROJECT ENGINEER	PROJECT NUMBER	SPONSOR	CONTRACT OR GRANT NUMBER	STARTING DATE	ENDING DATE	AWARD AMOUNT	SOURCE
DAMON	713176	NRL	N00173-80-C-0416	08-01-80	03-31-82	10K	03
MUNK	713206	ASD, WPAFB	F33615-80-C-1086	08-25-80	08-24-83	110K	02
MUNK	713302	NRL	N00173-80-C-0367	09-30-80	06-30-81	98K	03
RUDDUCK	713303	NADC	N62269-80-C-0384	09-22-80	09-30-81	50K	03
KSIENSKI/WALTON	713319	NRL	N00173-80-C-0466	09-17-80	11-30-80	10K	02
BURNSIDE	713321	NASC	N00019-80-C-0593	09-29-80	09-28-81	65K	02

APPENDIX III
REPORTS PUBLISHED BY ESL OCTOBER 1979 TO OCTOBER 1980

784299-9	CTS/COMSTAR COMMUNICATIONS LINK CHARACTERIZATION EXPERIMENT - FINAL, D.B. Hodge & R.C. Taylor, April 1980.
784346-9	A DIPOLE REFLECTOR PHASED ARRAY IMBEDDED IN DIELECTRIC SLABS, B.A. Munk & J.S. Ernst, October 1979.
784346-12	RADAR CROSS SECTION STUDIES AND CALCULATIONS - FINAL, B.A. Munk, C.J. Larson, J.F. Stosic & J.S. Ernst, December 1979.
784460-10	THE PRELIMINARY DEVELOPMENT AND APPLICATION OF A LONG BALUN FED ANTENNA FOR VIDEO PULSE RADARS, October 1979.
784569-11	ANALYSIS OF ELECTRICALLY THIN, DIELECTRIC LOADED CAVITY BACKED RADIATOR - FINAL, E.H. Newman, December 1979.
784701-6	A SYNERGISTIC INVESTIGATION OF THE INFRARED WATER VAPOR CONTINUUM - SEMIANNUAL, R.J. Nordstrom & R.K. Long, January 1980.
784786-2	THE ANALYSIS OF THE R.F. FIELD RESPONSE OF SOLID WIRES EXCITED BY LASER INDUCED ENDCAP CURRENTS, K.R. Demarest, January 1980. Dissertation.
784786-3	LASER INDUCED TRANSIENT EXCITATION OF CONDUCTING TARGETS - FINAL, W.H. Peake, J.G. Meadors, M.A. Poirier, J.D. Young & J.H. Richmond, March 1980.
529081-1	ANTENNA DESIGN FOR TERRASCAN RADAR SYSTEMS, J.D. Young, October 1979.
710816-4	IMPROVED IDENTIFICATION OF UNDERGROUND TARGETS USING VIDEO-PULSE RADARS BY ELIMINATION OF UNDESIRED NATURAL RESONANCES, I.L. Volakis, October 1979. Thesis.
710816-5	AN APERTURE-MATCHED HORN DESIGN, W.D. Burnside & C.W. Chuang, January 1980.
710816-6	JOINT SERVICES ELECTRONICS PROGRAM - ANNUAL, December 1979.
710816-7	A HYBRID MOMENT METHOD - GTD TECHNIQUE FOR ANALYSIS OF ANTENNAS MOUNTED ON OR NEAR CURVED SURFACES, L.W. Henderson & G.A. Thiele, April 1980. Thesis.
710816-8	A HYBRID METHOD OF MOMENTS TECHNIQUE FOR COMPUTING ELECTRO-MAGNETIC COUPLING BETWEEN TWO MONOPOLE ANTENNAS ON A LARGE

CYLINDRICAL SURFACE, S.A. Davidson & G.A. Thiele, April 1980. Thesis.

710964-4 HIGH FREQUENCY SCATTERING FROM A THIN LOSSLESS DIELECTRIC SLAB, K.W. Burgener, November 1979. Thesis.

710964-5 HIGH FREQUENCY SCATTERING BY A THIN LOSSLESS DIELECTRIC SLAB - SEMIANNUAL, W.D. Burnside & K.W. Burgener, February 1980.

711095-1 CYLINDER/JET INTAKE ANTENNA CODE - USER'S MANUAL - FINAL, W.D. Burnside & C.C. Huang, October 1979.

711305-3 A UNIFORM GTD SOLUTION FOR THE RADIATION FROM SOURCES ON A CONVEX SURFACE, P.H. Pathak, N.N. Wang, W.D. Burnside & R.G. Kouyoumjian, February 1980.

711305-4 RESEARCH ON NEAR FIELD PATTERN EFFECTS - FINAL, N. Wang & W.D. Burnside, November 1979.

711353-1 ON THE APPLICATION OF THE GTD-MM TECHNIQUE AND ITS LIMITATIONS, J.N. Sahalos & G.A. Thiele, October 1979.

711353-3 A HYBRID UTD-EIGENFUNCTION METHOD FOR SCATTERING BY A VERTEX, J.N. Sahalos & G.A. Thiele, June 1980.

711510-1 RAIN/RADOME EFFECTS ON ANTENNA SIDELOBE PERFORMANCE, F. Zayek & R.C. Rudduck, March 1980. Thesis.

711510-2 GTD COMPUTATION OF THE EFFECT OF A TUNNEL ON THE FEED SPILLOVER FOR AN OFFSET FED PARABOLIC REFLECTOR, E. Greer, December 1979.

711510-3 LOW SIDELOBE REFLECTOR ANTENNA STUDY FOR MILLIMETER WAVELENGTHS - FINAL, R.C. Rudduck & S.H. Lee, December 1979.

711559-2 A CAVITY-TYPE BROADBAND ANTENNA WITH A STEERABLE CORDIOID PATTERN - FINAL, B.A. Munk & C.J. Larson, December 1979.

711587-1 NEAR FIELD GAIN CORRECTION FOR STANDARD GAIN HORN ANTENNAS, H.H. Chung & R.C. Rudduck, March 1980. Thesis.

711587-2 MANUAL OF GAIN CORRECTION DATA FOR STANDARD GAIN HORN ANTENNAS, H.H. Chung & R.C. Rudduck, March 1980.

711587-3 MEASURING TECHNIQUES FOR THE CALIBRATION OF STANDARD GAIN HORN ANTENNAS, E.K. English, March 1980. Thesis.

711587-4 CALIBRATION OF RADIATION HAZARD METERS, W.H. Peake, April 1980.

711587-5 EVALUATION AND UPGRADING OF THE ANTENNA CALIBRATION FACILITY AT THE MEASUREMENT STANDARDS LABORATORY, NEWARK AIR FORCE STATION - FINAL, R.C. Rudduck, January 1980.

711588-1 PATTERN ANALYSIS OF A HORN ANTENNA IN THE PRESENCE OF OBSTACLES, W.D. Burnside & C.S. Kim, February 1980.

711588-2 AIRBORNE ANTENNA PATTERN CODE USER'S MANUAL, W.D. Burnside & T. Chu, March 1980.

711588-3 USER'S MANUAL FOR ARRAYS RADIATING IN A COMPLEX ENVIRONMENT WITH APPLICATION TO AIRCRAFT, R.J. Marhefka & W.D. Burnside, March 1980.

711588-5 ON-AIRCRAFT ANTENNA PATTERN PREDICTION STUDY - FINAL, W.D. Burnside & R.J. Marhefka, March 1980.

711679-2 AIRBORNE ANTENNA PATTERN CODE USER'S MANUAL, W.D. Burnside & T. Chu, March 1980.

711847-4 POINTING ACCURACY AND DYNAMIC RANGE IN A STEERED BEAM ADAPTIVE ARRAY, R.T. Compton, Jr., November 1979.

711847-5 COMMUNICATION APPLICATIONS OF ADAPTIVE ARRAYS - QUARTERLY, R.T. Compton, Jr., December 1979.

711847-6 ON GRATING NULLS IN ADPATIVE ARRAYS, A. Ishide & R.T. Compton, Jr., March 1980.

711847-7 COMMUNICATION APPLICATION OF ADAPTIVE ARRAYS - FINAL, R.T. Compton, Jr., March 1980.

711964-1 ELECTRICALLY SMALL ANTENNAS - SEMIANNUAL, J.H. Richmond & C.H. Walter, January 1980.

711964-2 ELECTRICALLY SMALL ANTENNAS - SEMIANNUAL, J.H. Richmond & C.H. Walter, August 1980.

712242-1 QUASI-OPTICAL TECHNIQUES FOR ANTENNAS AT UHF AND ABOVE - QUARTERLY, R.C. Rudduck & R.J. Marhefka, January 1980.

712242-2 QUASI-OPTICAL TECHNIQUES FOR ANTENNAS AT UHF AND ABOVE - QUARTERLY, R.C. Rudduck & R.J. Marhefka, April 1980.

712242-3 QUASI-OPTICAL TECHNIQUES FOR ANTENNAS AT UHF AND ABOVE - QUARTERLY, R.C. Rudduck & R.J. Marhefka, July 1980.

712242-4 GTD ANALYSIS OF REFLECTOR ANTENNAS WITH GENERAL RIM SHAPES-NEAR AND FAR FIELD SOLUTIONS, S.H. Lee, September 1980. Dissertation.

712331-2 AIRBORNE VHF RADAR MEASUREMENTS OF MOVING TACTICAL GROUND TARGETS, E.K. Walton, March 1980.

712331-3 GROUND BASED VHF, UHF, AND X-BAND RADAR MEASUREMENTS OF MOVING TACTICAL GROUND TARGETS, E.K. Walton, March 1980.

712351-1 RADIATION CHARACTERISTICS OF McDONNEL DOUGLAS ANTENNA/ RADOME CONFIGURATIONS - FINAL, C.J. Larson & B.A. Munk, November 1979.

712352-1 SURFACE SHIP TARGET CLASSIFICATION USING H.F. MULTI-FREQUENCY RADAR - FINAL, E.K. Walton & J.D. Young, May 1980.

712527-1 THE HIGH-FREQUENCY RADIATION PATTERNS OF A SPHERIOD-MOUNTED ANTENNA, C.C. Huang, N. Wang & W.D. Burnside, March 1980.

712680-1 AN ANALYSIS OF THE EFFECTS OF A FLAT L-SHAPED ROOF-TOP ON DIRECTION FINDING LOOP PERFORMANCE - FINAL, E.H. Newman, May 1980.

712684-1 USE OF AN ADAPTIVE ARRAY IN A FREQUENCY-SHIFT KEYED COMMUNICATION SYSTEM, E.C. Hudson, August 1980. Thesis.

712684-2 ADVANCED ADAPTIVE ANTENNA TECHNIQUES - QUARTERLY, R.T. Compton, Jr., August 1980.

712684-3 THE EFFECT OF DIFFERENTIAL TIME DELAYS IN THE LMS FEEDBACK LOOP, R.T. Compton, Jr., September 1980.

712949-1 PROPAGATION OF SURFACE WAVES ON A BURIED COAXIAL CABLE WITH PERIODIC SLOTS, J.H. Richmond, N.N. Wang & H.B. Tran, July 1980.

712949-2 A PORTED COAXIAL CABLE EMBEDDED IN LOSSY EARTH FOR USE AS AN INTRUSION SENSOR - QUARTERLY, R.J. Garbacz, July 1980.

712978-1 PLANE MULTILAYER REFLECTION CODE, E.H. Newman, July 1980.

479X-7 A COMPUTATIONAL MODEL FOR SUBSURFACE PROPAGATION AND SCATTERING FOR ANTENNAS IN THE PRESENCE OF A CONDUCTING HALF SPACE, C.W. Davis, III, October 1979. Dissertation.

APPENDIX IV
ESL PAPERS PUBLISHED OCTOBER 1979 TO OCTOBER 1980

CHARACTERISTIC MODES OF A SYMMETRIC WIRE CROSS, R.J. Garbacz & E.H. Newman, Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 5, pp. 712-715, September 1980.

CONSIDERATIONS FOR EFFICIENT WIRE/SURFACE MODELING, E.H. Newman & D.M. Pozar, Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 1, pp. 121-125, January 1980.

ON THE CYLINDRICAL AND SPHERICAL WAVE SPECTRAL CONTENT OF RADIATED ELECTROMAGNETIC FIELDS, E. Bello Ojeba & C.H. Walter, Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-27, No. 5, pp. 634-639, September 1979.

A DIFFRACTION COEFFICIENT FOR A CYLINDRICALLY TRUNCATED PLANAR SURFACE, C.W. Chuang & W.D. Burnside, Reprinted in Transactions on Antennas and propagation, Vol. AP-28, No. 2, pp. 177-182, March 1980.

ON GRATING NULLS IN ADAPTIVE ARRAYS, A. Ishide & R.T. Compton, Jr., Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 4, pp. 467-475, July 1980.

GREEN'S FUNCTION TECHNIQUE FOR NEAR-ZONE SCATTERING BY CYLINDRICAL WIRES WITH FINITE CONDUCTIVITY, J.H. Richmond, Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 1, pp. 114-117, January 1980.

IMPROVED FEEDBACK LOOP FOR ADPATIVE ARRAYS, R.T. Compton, Jr., Reprinted in IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-16, No. 2, pp. 159-168, March 1980.

MUTUAL IMPEDANCE BETWEEN VERTICAL DIPOLES OVER A FLAT EARTH, J.H. Richmond & E.H. Newman, Reprinted in Radio Science, Vol. 14, No. 6, pp. 957-959, November-December 1979.

NEAR-FIELD PATTERN ANALYSIS OF AIRBORNE ANTENNAS, W.D. Burnside, N. Wang & E.L. Pelton, Reprinted in IEEE Transactions on Antennas and Propagation, Vol. AP-28, No. 3, pp. 318-327, May 1980.

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THE POWER-INVERSION ADAPTIVE ARRAY: CONCEPT AND PERFORMANCE, R.T. Compton, Jr., Reprinted in IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-15, No. 6, pp. 803-814, November 1979.

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SCAN INDEPENDENT PHASED ARRAYS, B.A. Munk T.W. Kornbau & R.D. Fulton, Reprinted in Radio Science, Vol. 14, No. 6, pp. 979-990, November-December 1979.

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